Exploring Concurrent Interrelations Between Symbolic and Social-Cognitive Domains in Autistic and Neurotypical Children

Cheriece K. Carter

This thesis is submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

Lancaster University

Department of Psychology

March 2024

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Declaration

I declare that this thesis is entirely my own work completed under the supervision of Calum Hartley and Charlie Lewis (author contributions are listed at the start of chapters). None of the work in this thesis has been submitted elsewhere in support of application for another degree at this, or any other, institution.

The parts of this thesis that are presented in publishable paper format, or have been published in academic journals, are indicated at the beginning of each relevant chapter. This thesis is 63,564 words including footnotes, tables, figures, and citations, thus does not exceed the permitted maximum. The word count does not include items that do not comprise the main text of the thesis, such as the Table of Contents, Title Page, Declaration, List of Tables, List of Figures, Acknowledgements, Abstract, Appendices, or Bibliography.

- Cheriece Carter (2024)

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List of Abbreviations

2-D	Two-dimensional
3-D	Three-dimensional
AAC	Augmentative Alternative Communication
ADI-R	Autism Diagnostic Interview-Revised
ADOS-2	Autism Diagnostic Observation Schedule Version 2
ASD	Autism spectrum disorder
CARS-2	Childhood Autism Rating Scale Version 2
CL	Contrasting labels
IJA	Initiation of joint attention
IQ	Intelligence quotient
JASPER	Joint Attention, Symbolic Play, Engagement, and Regulation
ME	Mutual exclusivity
MSEL	Mullen Scales of Early Learning
NDBI	Naturalistic Developmental Behavioural Intervention
NT	Neurotypical
PECS	Picture Exchange Communication System
RJA	Response to joint attention
SL	Same labels
ToM	Theory of mind

Acknowledgements

It’s been one heck of a journey, but I did it… My thesis is finally complete, after seven years, six chapters, five [million] technical issues, four research projects, three house moves, two pregnancies, and one global pandemic! Through all of this, I’ve been extremely fortunate to have the most incredible support network. Although it’s not possible to acknowledge each person individually, I want to express my everlasting gratitude to everyone who has played a part in making this achievement possible.

Above all, I would like to thank my Mum, Martine, for encouraging me to do a PhD in the first place, always being there for me, and saving me an absolute fortune in childcare fees! Your love, sacrifices, and generosity have not just shaped my academic journey, but my entire life. I love and appreciate you so much, and hope I’ve made you proud. During my career, I’ve had the pleasure and privilege of working with so many incredible children, who inspired me to be curious, ask questions, and really listen to the answers. Thank you for kick-starting this whole adventure; you will forever hold a place in my heart. Now I have my own children, I feel truly complete and have a whole new perspective on life. Eddie and Daisy, I love you both unconditionally and feel blessed to be your Mum. Thank you for being with me every step of the way. Of course, I would like to thank the love (and sometimes bane!) of my life Aaron for all the hours you’ve spent drawing symbols for my research projects, listening to presentations you don’t understand, and making sure I never go hungry! Thanks for always believing in me. You’ve seen every side of me, and I hope you’ll always be by my side. I love you and I love the life we’ve built together.

I’m especially grateful to Dr Calum Hartley for being the most patient and supportive supervisor. You’ve been an incredible mentor and I couldn’t have done this without your expertise, encouragement, and endless positivity. Thank you for pushing me, but not letting me fail, always reminding me to: *“Just keep swimming…”* Your willingness to adjust in

response to the challenges and uncertainties of life has been a constant source of inspiration and has motivated me to see this through to the end. During my time at Lancaster, I've had the pleasure of meeting and collaborating with so many wonderful people in the Department of Psychology. A heartfelt shout out to Dr Bethany Wainwright, Dr Charlotte Rothwell, Dr Leigh Keating, and Dr Rachael Cheung for their camaraderie and valuable input over the years. I would also like to thank Clare Race and Nadine Wilson for their continued support and guidance, and Barrie Usherwood for his invaluable technical assistance. I would specifically like to thank the children, parents, and staff at Park Community Academy, Hawes Side Nursery, and Hillside Specialist School. Without you, this research would not have been possible! Special thanks to Vicky Heaney, Amy Randall, and Steph Brown for welcoming me into your settings and being so supportive.

Of course, a very big thank you to my glamorous Nana – the legendary Queenie – for your warm hugs, words of wisdom and much-needed pep talks (and biscuits!) to reach the finish line. Last, but not least, I also want to thank my best friends for always keeping it real and being my biggest supporters. Ellie, you're like a sister to me and I can't imagine my life without you. You're a breath of fresh air and you just get it. Thanks for keeping me sane in an insane world. Kasha, your loyalty is second to none and I really value your friendship. Whatever the weather, we walked and talked for miles to get our babies to sleep! We probably didn't finish most of the conversations we started, but you were right about me finishing this PhD… my Daruma finally has two eyes!

Dedication

This thesis is dedicated to the one and only Kenny Carter, who taught me to question everything, and introduced me to all things autism.

Publications

Carter, C. K., & Hartley, C. (2021). Are children with autism more likely to retain object names when learning from colour photographs or black-and-white cartoons? *Journal of Autism and Developmental Disorders, 51*(9), 3050–3062. https://doi.org/10.1007/s10803-020-04771-2

Thesis Abstract

To advance understanding of relationships between symbolic communication systems, this thesis examines concurrent predictive associations between social-cognitive skills, picture comprehension and production, and symbolic play in autistic and neurotypical children. As social communication and language abilities are intimately related in early neurotypical development, and may provide a vital scaffold for play and pictorial domains, delays and differences in these scaffolding bases – such as those commonly observed in autism – could have critical downstream consequences for non-linguistic symbolic domains. Studies 1 and 2 investigate predictive relationships between symbolic domains (social communication, play, and pictures) and other individual differences (e.g. language abilities, non-verbal intelligence, and fine motor skills) in neurotypical 2–5-year-olds (Study 1) and language-delayed autistic 4–11-year-olds (Study 2). Study 1 reports bidirectional interrelationships between pictorial, play, and social communication domains, suggesting that these modules of symbolic development may be underpinned by shared factors in neurotypical children. In Study 2, pictorial and symbolic play abilities were bidirectionally related, and both these domains were predicted by social communication and/or social scaffolding, although proficiency in play and pictorial domains did not appear to reciprocally contribute to social communication abilities.

Study 3 explores whether there are differences in the presence, direction, and magnitude of predictive relationships between symbolic domains in autistic and neurotypical children matched on language comprehension (*M* age equivalent = autistic: 44.11 months; neurotypical: 44.30 months). Although social communication skills predicted play and pictorial abilities in neurotypical children, this was not observed in autistic children. Evidence for possible relationships between play and pictorial domains was identified in neurotypical children, but not autistic children. These findings suggest that non-linguistic

symbol systems (e.g. play and pictures) in neurotypical children are interdependent and mediated by social-cognitive abilities. However, in autistic children, symbolic domains may be relatively independent and the lack of relationships with social communication skills potentially implicates a different route to acquiring symbol systems. Study 4 examines how autistic children and language-matched neurotypical children (*M* age equivalent = autistic: 43.60 months; neurotypical: 44.75 months) learn novel vocabulary from pictures and how this is influenced by iconicity (i.e. the extent to which a symbol resembles its intended referent). Autistic children achieved significantly greater retention accuracy when learning object names from highly iconic colour photographs compared to less iconic black-and-white cartoons and, surprisingly, responded more accurately than neurotypical children when learning from photographs. These findings suggest that learning words from pictures may be more cognitively challenging for neurotypical children than learning words from objects, and that autistic children benefit from greater iconicity when learning words from pictures.

Overall, this thesis demonstrates differences in the relatedness of symbolic domains between populations. Play and pictures were consistently interrelated and supported by social communicative abilities in both neurotypical and autistic children. While bidirectional relationships between social communication, play, and pictures were observed in neurotypical children, this was not the case for autism. Direct population comparisons involving language-matched participants drawn from both populations suggest that understanding of non-linguistic symbols is interdependent and mediated by social-cognitive abilities in neurotypical children. In contrast, symbolic domains appeared to be relatively more independent and less consistently scaffolded by social skills in autism. At an applied level, these results have important implications for the design/delivery of early education practices and clinical interventions, and provide a data-grounded rationale for using colour photographs when administering picture-based interventions for autistic individuals.

Epigraph

"The birth of a symbolic mind may be the most fundamental milestone in human development as it transforms all cognition once it is achieved."

(Callaghan, 2008, p.21)

Chapter 1: Introduction and Literature Review

In the first few years of life, children are introduced to a wide range of symbolic artifacts and make rapid progress toward understanding and using a variety of symbol systems including gestures, words, and pictures (DeLoache, 2000). This capacity to create and comprehend symbols is regarded as a uniquely human ability that has irrevocably transformed our species (Deacon, 1997), expanding our intellectual horizons, liberating us from the constraints of time and space, and enabling us to acquire information about reality in the absence of direct experience (DeLoache, 2004). In contemporary psychology, a symbol is defined as ‘something that someone intends to represent something other than itself’ (DeLoache, 2004, p. 66). Beneath the surface simplicity of this definition lies complexity and nuance. At their very core, symbols are social tools which can be used creatively and flexibly to communicate (Tomasello, 1999). Importantly, although some symbols have a close perceptual correspondence with their intended referents (e.g. photographs and scale models), physical resemblance is not an essential prerequisite for an entity to serve a symbolic function (Browne & Wooley, 2001; DeLoache, 2004; Huttenlocher & Higgins, 1978). The one condition that is both necessary and sufficient to establish a symbolic relation is the human intention to communicate. When something is deemed to be a symbol, this indicates “…there is some social convention, tacit agreement or explicit code which establishes the relationship that links one thing to another” (Deacon, 1997, p.71). For example, the word ‘lion’ refers to a type of animal, both picture and word represent courage, and the well-known video clip of a roaring lion designates a motion picture company (Fein, 1987). Thus, technically anything can serve as a symbol, but the transformation from entity to symbol requires purposeful creation (DeLoache et al., 2003).

Developing symbolic competence is a crucial milestone that enables children to communicate effectively and fully participate in society (Callaghan et al., 2011; Klin et al., 2002). To navigate the modern social world, children must learn to interpret and produce a variety of symbols, including symbolic gestures, speech, writing, models, maps, and pictures (Ittelson, 1996; Wetherby et al., 2000). Irrespective of form, children must recognise how a symbolic entity relates to its function, how that function is determined by *someone's* intention, and identify what *the something other than itself* denotes (Apperly, 2004). Developments in these components of children's symbolic understanding may apply across all symbols, or possibly emerge at different times and in different ways across a range of symbol types. These complexities mean that the course of children's developing understanding of symbols is likely to consist of many distinct achievements over several years (DeLoache & Burns, 1994; Jolley, 2008; Liben, 1999). For example, while children typically start using words to request and identify specific things in the environment at approximately 12 months old (Tager-Flusberg et al., 2009; Zubrick et al., 2007), and begin to use objects 'as if' they were something else during imaginative play at around 18 months old (Bergen, 2002; Lillard, 2017; McCune, 1995), their ability to use and produce pictures referentially becomes established much later at approximately three years old (Callaghan, 1999; Jolley & Rose, 2008; Nelson, 2007).

Development in symbolic understanding presents challenges for some neurodiverse populations such as children diagnosed with autism spectrum disorder (ASD) – a heterogenous neurodevelopmental condition characterised by difficulties in communication and social interaction, and the presence of restricted interests and repetitive behaviours (American Psychiatric Association, 2013). According to the DSM-5, diagnosis-defining social difficulties can manifest in a variety of ways, including differences in eye contact and body language, poor understanding and use of gestures/facial expressions, failure to initiate and/or respond to social interactions, and difficulties developing and maintaining relationships (American Psychiatric Association, 2013). Diminished social motivation is also a prominent and persistent characteristic associated with this population (Chevallier et al., 2013). Autistic individuals generally display reduced attention to social stimuli (e.g. faces and gaze direction) compared to non-social stimuli (Chawarska et al., 2015; Dawson et al., 2005), and demonstrate significant disruptions in seeking social interactions and maintaining social engagement (Chevallier et al., 2012; Liebal et al., 2008). Furthermore, they often show profound delays and differences in symbolic communication, demonstrate severe language difficulties (Anderson et al., 2007; Tager-Flusberg & Kasari, 2013), a reduced propensity to engage in spontaneous pretend play (Hobson et al., 2013; Jarrold, 2003), and differences in understanding pictures (Hartley & Allen, 2014a, 2014b, 2015a, 2015b; Preissler, 2008).

Although research has consistently established difficulties and differences across multiple symbolic domains in ASD, including language, symbolic play, and pictures, the specific underpinning mechanisms and their interactions with broader cognitive and communicative abilities are not fully understood. Considering the diagnosis-defining differences in social-cognition and social-motivation in ASD, symbolic development in this population could potentially follow one of two patterns. Non-linguistic symbol systems could develop independently and be unrelated to linguistic and social-cognitive abilities (Mundy, 1995), which would result in an uneven ability profile whereby a child could have sophisticated play and/or pictorial skills in conjunction with relatively underdeveloped language. Alternatively, symbolic understanding of play and pictures may be acquired via the same route as in neurotypical development, with language and/or social communication mediating learning (Anderson et al., 2007). If this is the case, autistic children’s symbolic play and picture abilities would develop at a rate commensurate with expectations based on their current language ability. Empirical investigation of these key issues, in the present thesis, is necessary to advance theoretical understanding of the relationships between symbolic abilities and individual differences in neurotypical and autistic children, establish how symbolic domains concurrently interrelate in both populations, and potentially inform the design and delivery of clinical and educational interventions.

This literature review begins with an overview of the developmental trajectory of social communication, language, play, and pictures in neurotypical children, and identifies some of the factors that influence receptive and expressive abilities in each of these symbolic domains. It goes on to briefly review three theoretical models of symbolic development, before examining the same issues in relation to autistic development. Finally, an outline of the four studies that comprise the thesis is presented.

Social Communication in Neurotypical Development

Social communication refers to the understanding and use of verbal and non-verbal communication in social situations to make requests, indicate needs and feelings, relate to other people, and develop meaningful relationships (Jethava et al., 2022). Social communication encompasses many fundamental components, including *social interaction* (i.e. the behaviour of individuals participating in a joint activity), *social cognition* (i.e. the cognitive processes required during interactions, including emotional competence, the ability to attribute mental states to oneself and others, executive functioning, and joint attention), *pragmatics* (i.e. recognising and employing social rules of conversation, including turn-taking, topic maintenance, and conversational repairs), and *receptive and expressive language abilities* (i.e. comprehending and producing speech). Each of these elements are important for enabling successful and appropriate reciprocal exchanges. When interacting with others, children must learn to appreciate societal norms and practices (Tomasello, 2003a), make inferences to understand why a conversational partner is behaving in a certain way and respond accordingly (Carpenter et al., 1998), comprehend the speech of others, and construct suitable replies to clearly convey their own ideas and feelings (Conti-Ramsden & Durkin, 2012; Fujiki & Brinton, 2009).

Social communication skills include a wide repertoire of behaviours including eye gaze, imitation, social smiling, and joint attention (Wetherby et al., 2007). In neurotypical children, these prelinguistic abilities follow a predictable developmental trajectory (Mundy et al., 2007; Striano et al., 2009). Neonates preferentially orient towards and maintain visual fixation on faces over non-faces (Goren et al., 1975; Shultz et al., 2018; Valenza et al., 1996) and imitate specific adult gestures, such as tongue protrusion and head movements (Meltzoff & Moore, 1989; Nagy et al., 2020). Engagement in reciprocal eye contact with caregivers occurs at about four weeks old (Mirenda et al., 1983) and supports the regulation and management of social interactions (Feldman, 2007; Lee et al., 1998). Social smiles (i.e. smiling with eye contact directed toward a social partner) emerge at around 6–8 weeks old and become more communicative as infants mature (Malatesta et al., 1989; Venezia et al., 2004). During early parent-infant interactions, caregivers model, scaffold, and reinforce their infants' emerging skills to promote their socio-cognitive and language development (Bornstein & Tamis-LeMonda, 1989; Landry et al., 2001). In this collaborative process, adults can shape infants' development, and infants can influence the quality of their interactions with others.

Between one and two months old, infants contribute to and influence social exchanges with their caregivers using social smiling (Messinger & Fogel, 2007; Ruvolo et al., 2015; Rochat & Striano, 1999). This universally regarded expression of pleasure "occurs when an infant with an initially expressionless face examines the face of another person, his face and eyes then light up, and the corners of his mouth pull upward" (Anisfeld, 1982, p. 387). Although smiling is observed in newborns from birth, these first smiles are predominantly reflexive and tend to occur during sleep (Messinger et al., 2002). Social smiles develop during interaction, and are simultaneously experiential and social, serving as a signal to the self as well as the interactive partner (Messinger & Fogel, 2007), communicating positive feelings, facilitating social cohesion, and eliciting reciprocal responses from adults (Caulfield, 1996). As early as 10 months old, infant smile production is partly dependent on the presence of a social partner to observe the facial expression (Jones et al., 1991), indicating an emerging control of smiling to communicate happiness to others. With development and maturity, smiles can be willingly produced in the absence of positive emotions (Krumhuber & Manstead, 2009), and research evidence indicates that social motivation can have a greater influence than positive emotional experience in determining when and how children and adults smile (Fernandez-Dols & Ruiz-Belda, 1995; Holodynski, 2004).

Until approximately nine months old, infants interact with people and objects in their environment through dyadic interactions (Hoehl & Striano, 2015). From this age, refinements in motor control afford important opportunities for interaction and communication, including giving and showing objects to others (Cameron-Faulkner et al., 2015; Moreno-Núñez et al., 2020). Between 9–12 months, infants are increasingly capable of using facial expression, eye gaze, gestures, and vocalisations to co-ordinate a triadic attentional frame between themselves, an object, and a communicative partner (Bakeman & Adamson, 1984; Hobson, 2005; Hoehl & Bertenthal, 2021; Tomasello, 1995). These developing skills enable individuals to reliably follow the gaze of a social partner (Scaife & Bruner, 1975; Senju & Csibra, 2008), co-ordinate their attention to an object or event of mutual interest and realise that they are both attending to the same thing – a process known as 'joint attention.'

Joint attention is a goal-oriented behaviour which refers to infants' capacity to co-ordinate attention with a social partner to establish a common point of reference, and share information and experiences (Mundy, 2016; Mundy et al., 2009). Joint attentional episodes support and scaffold pre-verbal infants' ability to understand other people as intentional agents, interpret communicative intentions, learn to use tools and symbols, and begin to link words with referents (Baldwin, 1995; Bruner, 1983; O'Madagain & Tomasello, 2021; Tomasello & Farrar, 1986). Early development of joint attention skills manifests in two types of behaviours: response to joint attention (RJA) and initiation of joint attention (IJA). RJA refers to an infant's ability to follow the gaze, head turn, and pointing gestures of a social partner (Hobson & Hobson, 2007; Scaife & Bruner, 1975), whereas IJA relates to an infant's use of attention-directing behaviours, such as pointing, showing and gaze shifting, to spontaneously share their interest in an object/event with another person (Cameron-Faulkner et al., 2015; Mundy et al., 1986). Although infants are not explicitly taught to socially co-ordinate their attention with others, they gradually develop the capacity to consider and adopt the viewpoint of others as they process information in episodes involving RJA and IJA (Kokkinaki et al., 2023). Research indicates that neurotypical development of RJA begins early in infancy and is characterised by increasingly consistent and accurate attention co-ordination responses between 2–12 months-old (Mundy et al., 2007; Gredebäck et al., 2010). These response behaviours to joint attention bids are present before infants can initiate this type of interaction themselves (Mundy & Jarrold, 2010) – for example holding out and giving as a form of declarative behaviour emerges at approximately 10 months old (Bates, 1976; Cameron-Faulkner et al., 2015) and index finger pointing between 8–12 months in neurotypical infants (Carpenter et al., 1998; Beuker et al., 2013). While RJA generally occurs much earlier in ontogeny than IJA, most children demonstrate proficiency in both skills by the age of two years old (Carpenter et al., 2002).

Language in Neurotypical Development

Language – arguably the most important symbol system – comprises arbitrary symbols (e.g. spoken and written words) used by humans to communicate or express ideas and thoughts to others. Both receptive and expressive aspects of language are important to an individual's overall language skills. While expressive language refers to a child's use of words and gestures to convey meaning to others, receptive language refers to a child's ability to accurately comprehend what is said, written, or signed by others. Although there is substantial individual variability around the trajectory of language development, comprehension skills usually precede production skills (Conti-Ramsden & Durkin, 2012; Fenson et al., 1994). Early signs of language comprehension are evident between 6–9 months, when infants begin to respond to their name (Tincoff & Jusczyk, 1999) and associate specific words and objects in familiar contexts (Bernhardt et al., 2007). Most neurotypical children produce their first word around their first birthday (Tager-Flusberg et al., 2009; Zubrick et al., 2007), and soon after achieving this milestone, learn to say around ten words per month until they acquire approximately 50 words. Following this, productive vocabulary begins to accumulate at a faster pace of 30+ words per month (Benedict, 1979; Goldfield & Reznick, 1990). Although children make remarkable progress in their ability to understand and produce words between the ages of one and two years (Fenson et al., 1994), they continue to demonstrate an advantage for receptive over expressive abilities. At 12 months old, a neurotypical child who can understand approximately 50 words may only utter one or two words; at 24 months old, word comprehension increases to around 370 words and word production to around 270 words (Hamilton et al., 2000).

Word learning is one of the core components of language acquisition (Hauser et al., 2002; Pinker & Jackendoff, 2005). To acquire vocabulary, children must associate the phonology and meaning of a newly heard word and form a lasting connection between the two. This multi-stage process involves identification of intended meaning (referent selection) and storage of the word-referent pairing in memory for later retrieval (retention). In everyday life, children are exposed to hundreds of words every hour (Hart & Risley, 1995; Samuelson & McMurray, 2017; Speigel & Halberda, 2007) and each newly heard word could refer to multiple potential referents (Cartmill et al., 2013; Yu & Ballard, 2007). Despite this problem of ‘referential ambiguity’ (Quine, 1960), neurotypical three-year-olds are remarkably capable of mapping novel words onto unnamed objects with minimal exposure (Horst & Samuelson, 2008; Spiegel & Halberda, 2011). This process is known as ‘fast mapping’ and was first demonstrated by Carey and Bartlett (1978) in an experiment where three-year-olds were asked to get “the chromium tray, not the blue one, the chromium one.” Participants successfully mapped the unfamiliar label (‘chromium’) to the intended referent (an olive-green tray). Subsequent studies have documented fast mapping proficiency across a range of categorical domains (Heiback & Markman, 1987; Twomey et al., 2014) and age groups (Halberda, 2003; Mervis & Bertrand, 1994), including neurotypical children as young as 6- and 13-months-old (Friedrich & Friedrici, 2011; Kay-Raining Bird & Chapman, 1998; Taxitari et al., 2019; Woodward et al., 1994).

While some theories argue that young children utilise internal, innate biases to constrain the number of potential referents in their environment and successfully determine the meaning of a word (Golinkoff et al., 1994; Markman & Wachtel 1988), other perspectives emphasise the importance of socio-pragmatic cues (Baldwin, 1993; Tomasello, 2000). Cross-situational statistics are also regarded as helpful for resolving the word-referent problem (Horst et al., 2010; Smith et al., 2011). Over multiple learning instances, children accrue data and recognise patterns which help them determine that certain words and objects always co-occur (Smith & Yu 2008; Romberg & Saffran, 2010). Rather than viewing these as competing accounts, the Emergentist Coalition Model (Hollich et al., 2000) presents a more unified theory, proposing that children have access to multiple cues to identify word-referent mappings, including cognitive biases, social-pragmatic factors, and global attentional mechanisms.

According to Markman (1990) children assume that: i) words denote whole objects rather than parts of objects (*whole object assumption*), ii) labels refer to objects of the same taxonomic category (*taxonomic assumption*), and iii) each referent only has a single label (*mutual exclusivity assumption*). Thus, when children hear “Bring me the chromium one, not the blue one” they may use the familiar term ‘blue’ to form a quick hypothesis about the meaning of the unfamiliar word ‘chromium,’ and successfully deduce that it refers to the property of an object, is a colour word, and is constrained to the non-blue item (Carey & Bartlett, 1978). By the age of two years, neurotypical children utilise the mutual exclusivity (ME) principle to identify referents of novel words (Carey, 1978; Merriman & Bowman, 1989). This bias could be a specifically linguistic phenomenon, a lexical mechanism that is either an innate preference or acquired during language development (Mervis et al., 1994), or a by-product of general learning processes that guide children to prefer one-to-one mappings as part of a general tendency to exaggerate regularities (Markman, 1992). Another possibility suggests that ME relates to children’s expectations about the communicative intentions and behaviours of others (Clark, 1997). Children anticipate that speakers’ utterances will be informative, relevant, and understandable, therefore they expect speakers to use familiar words to refer to familiar things (Bloom, 2000).

To investigate children’s use of ME, researchers typically present a single unfamiliar object alongside one or more familiar objects and ask participants to identify the referent of a novel word. Behavioural paradigms require children to point to or hand the target object to an experimenter (e.g. Hartley et al., 2019; Merriman & Bowman, 1989), whereas eye-tracking paradigms require children to look at the target object (Halberda, 2003; Mathée-Scott et al., 2021; Twomey et al., 2018). As children already know the name(s) of the familiar object(s), they can use ME to deduce that the novel word (e.g. “dax”) must refer to the novel object. By 24 months old, neurotypical children are capable of fast-mapping novel words via disambiguation (Axelsson et al., 2012; Bion et al., 2013; Horst & Samuelson, 2008; Horst et al., 2010), although there is evidence indicating this ability emerges much earlier between 12–17 months old (Halberda, 2003; Houston-Price et al., 2010; Pomiechowska et al., 2021).

According to social-pragmatic accounts, language acquisition is an inherently social phenomenon, and children acquire words by engaging in episodes of joint attention with mature language users (Bruner, 1983; Tomasello, 2003a). Monitoring the referential intentions of others during discourse through attending to social cues (e.g. gaze, gesture, posture, and facial expression) can help children to constrain the meanings of novel words (Baldwin, 1993; Bloom, 2000; Brand, 2000; Moore et al., 1999; Tomasello, 2000). For instance, when hearing a novel word, neurotypical 18–24-month-olds spontaneously refer to a speaker's face and utilise gaze direction as a mapping cue (Baldwin, 1991; Preissler & Carey, 2005). Other empirical evidence demonstrates that by two years, children will associate a novel label with the object a speaker is looking at, even if there is another appealing object available (Moore et al., 1999) or there is a lack of temporal contiguity between the naming and appearance of the target object (Tomasello & Barton, 1994). Together, these studies suggest that young children privilege a speaker's intention when learning words, even when intentional cues contradict associations (Diesendruck et al., 2004). Between 2- and 4-years-old, children are increasingly able to integrate multiple social cues simultaneously into a coherent interpretation of the speaker's referential intentions, such as eye gaze, utterance, and pragmatics (Grassmann et al., 2009; Nurmsoo & Bloom, 2008).

Overall, numerous studies demonstrate that the presence of specific social cues, including gaze and pointing, mediate children's fast-mapping abilities during referent selection tasks (Akhtar et al., 1996; Brooks & Meltzoff, 2008; Morales et al., 2000; Striano et al., 2006; Tenebaum et al., 2014). Therefore, social-pragmatic theories argue that the process of resolving referential ambiguity is scaffolded through the collaborative social interaction between infant and caregiver. Adults provide social cues that guide children towards the correct referent, and introduce the relevant verbal label for the child, who is already focused on the referent (Nelson, 2007). Thus, word learning is a by-product of social exchanges that emerges on a timescale which is contingent on children's developing socio-cognitive skills; towards the end of the first year of life, early acquisition of spoken language and intention-reading abilities coincide (Tomasello, 2003a). In neurotypical children, joint attention skills correlate with early language learning and strongly predict subsequent language development (Carpenter et al., 1998; Morales et al., 1998; Mundy & Gomes, 1998).

Identification of meaning is an important first step for word learning, but children must also *retain* word meanings in memory to acquire vocabulary. Despite achieving ceiling-level accuracy in referent selection tasks, neurotypical 2-year-olds often forget new words after just a 5-minute delay (Axelsson et al., 2012; Horst & Samuelson 2008; Horst et al., 2010; Kucker & Samuelson, 2012). Similar findings have been reported in 6-month-olds (Friedrich & Friederici, 2011) and 3-year-olds (Vlach & Sandhofer, 2012). This suggests that the rapid process of mapping a novel name to a referent emerges in the moment (i.e. fast mapping), whereas the process of encoding a robust representation of a word-referent association develops more gradually over an extended time scale (i.e. slow learning; Kucker et al., 2015; McMurray et al., 2012; Samuelson & McMurray, 2017). According to the dynamic associative account, retention is underpinned by associative learning mechanisms that enable children to detect and accumulate statistical co-occurrences between words and environmental features over time and contexts (McMurray et al., 2012). Over multiple learning instances, 12- and 14-month-old infants can successfully associate words and their corresponding referents in experimental tasks that require them to attend to and aggregate cross-situational statistical information (Gómez & Lakusta, 2004; Smith & Yu 2008).

Symbolic Play in Neurotypical Development

The developmental trajectory of play in neurotypical children generally progresses through three main stages: sensorimotor play, functional play, and symbolic play (Piaget, 1952). In early infancy, play is sensorimotor in nature and typically involves action, pleasure seeking, and exploring objects by mouthing, grasping, and banging (Belsky & Most, 1981; Casby, 2003; Freeman & Kasari, 2013; Largo & Howard, 1979). At approximately nine-months-old, infants begin to manipulate objects in a more appropriate and conventional manner, according to their specific properties, for instance stacking blocks and rolling balls (Belsky & Most, 1981; Fein, 1981; Largo & Howard, 1979). Children show an early understanding of pretence from approximately 16-months-old (Bosco et al., 2006; Onishi et al., 2007), and begin to engage in symbolic play around the age of 18-months (Fenson & Ramsay, 1981; Leslie, 1987; Weisberg, 2015). Unlike other types of playful activities, such as constructive or physical play, symbolic play involves individuals acting 'as if' and using objects or actions to symbolise other entities, properties, or roles (Garvey, 1990; Lillard et al., 2013). Children can impose a layer of pretence over reality to immerse themselves in imaginative scenarios and temporarily suspend the constraints of reality. This type of play involves three forms: object substitution (e.g. using a plastic cup as a telescope), the attribution of false properties (e.g. pretending a doll is ill), and the attribution of presence to imaginary objects (e.g. driving a truck over an invisible bridge; Leslie, 1987).

From 18–30 months old, neurotypical children employ substitutions during play, using an object beyond its conventional function to represent another. For example acting as if a banana is a telephone or pretending a cardboard box is a boat (Bergen, 2002; Lillard, 2017; McCune, 1995). As this coincides with the rapid expansion of children's object name vocabularies, the relationship between language and pretend play could reflect a shared symbolic function – e.g. the cardboard 'boat' and the word "boat" both represent a real boat

(Lillard, 1993; Pleyer, 2020). Consistent with this idea, when choosing substitute objects, children tend to apply specific constraints and select items that are more "symbol-like" (i.e. have minimal surface details and share a geometrical resemblance to the shape of the replaced object; Bates et al., 1979; Striano et al., 2001). For instance, a banana is more likely to be used as a telephone than a richly detailed toy vehicle. Between 3–5 years, more complex symbolic play activities emerge that necessitate use of imagination, such as pretending with invisible objects (Mitchell & Clark, 2015; Singer & Singer, 1990).

In neurotypical children, the onset of language, specifically the emergence of words, has been associated with the development of symbolic play (McCune, 1995). As children's play skills develop, there are reciprocal improvements in other developmental domains, as play is highly correlated with language and cognitive skills (Sigman & Ruskin, 1999; Thiemann-Bourque et al., 2012; Toth et al., 2006). In neurotypical 3–6-year-olds, higher language comprehension scores are linked to increased participation in complex social play, such as co-operative social pretend play, while lower language comprehension scores are associated with more frequent engagement in parallel play, where children play independently alongside others (Holmes et al., 2015). These findings corroborate previous research demonstrating a concurrent relationship between both receptive and expressive vocabulary and symbolic play skills in 1–6-year-olds (Christie & Roskos, 2009; Doswell et al., 1994; Lewis et al., 2000; Quinn et al., 2018). Despite abundant evidence indicating that children's pretend play, language, and symbolic understanding are strongly related (Lillard et al., 2013; Orr & Geva, 2015; Quinn et al., 2018; Smith & Jones, 2011; Zlatev & McCune, 2014), disentangling these correlations is challenging because very few studies provide evidence for predictive relationships (Russ & Wallace, 2013). Furthermore, since language and symbolic play both rely on the capacity for symbolic understanding (Pleyer, 2020), children must appreciate that a particular entity – for example a word or an object – can be substituted to symbolise something else or utilised as if it were something else (Fein, 1987).

Pretend play also fosters social opportunities for children to develop perspective-taking skills and engage in co-operative activities with shared intentions (Rakoczy, 2006; Vygotsky, 1978), with social-cognitive abilities strongly implicated in language development (Tomasello, 2008). Nevertheless, it has been argued that complex pretend play provides meaningful scaffolding opportunities for developing important linguistic and social-cognitive skills that directly contribute to children's language comprehension and production (Christie & Roskos, 2009; Langley et al., 2019; Nell et al., 2013, Quinn & Kidd, 2019; Trawick-Smith, 1998). This may be influenced by the language used during play with more competent play partners (Lillard et al., 2010) or when children discuss pretence with others outside of play (Bergen, 2002).

Pictorial Comprehension and Production in Neurotypical Development

Pictures – such as drawings, paintings, and photographs – are two-dimensional representations of real-world entities. As pictures are so prevalent and important in our everyday lives, it is easy to overlook their complexity and assume that "…anything so familiar must be simple" (Gibson, 1980, p. xvii). However, the development of pictorial understanding is a complex, multifaceted process that emerges and consolidates at different stages of development (Jolley, 2008). To understand and use pictures as symbols, a viewer must appreciate their inherently dual nature (Gibson, 1980; Sigel, 1978). While a picture is an object composed of markings on a surface, at the same time it is a representation of something other than itself (Ittelson, 1996). For example, a drawing of a daisy is a depiction of a flower *and* a pictorial surface marked with ink. Thus, a viewer must simultaneously "see" the physical surface and "see through" it to its depicted referent (DeLoache, 2005, p.

330) to successfully draw inferences from one to the other (DeLoache, 2002; DeLoache et al., 2003; Jolley, 2008).

The role of experience in the development of pictorial competence has been subject to considerable discussion. According to Gibson's resemblance theory (1971, 1979), picture perception is a bottom-up process. In this view, prior pictorial experience is not necessary for understanding pictures, as two-dimensional (2-D) representations practically afford the same higher-order invariant information as their corresponding three-dimensional (3-D) referents. Thus, children can perceive and analyse pictorial information in the same way as equivalent real-world scenes in their environment. In contrast, constructivist theories propose that picture perception is a top-down process (Goodman, 1976; Gombrich, 1974). According to this perspective, pictures are cultural conventions bound by specific rules that must be learned through experience to ensure individuals can use and understand the symbols relevant to their culture. The meaning of a picture is constructed by the viewer; what a person sees, or thinks they see, is filtered through their own experiences and expectations. It is difficult to resolve this long-standing debate with a simple, dichotomous answer, because more contemporary picture research reveals a complex interplay between innate and learned factors in children's development (Ganea et al., 2011; Simcock & DeLoache, 2006).

Studies investigating pictorial understanding in neurotypical infants demonstrate that three-month-olds can identify their mother's face in colour photographs (Barrera & Maurer, 1981; de Schonen & Mathivet, 1990) and 5-month-olds can recognise faces, objects, and abstract patterns in pictures (Dirks & Gibson, 1977; Rose, 1977), and discriminate between two- and three- dimensional stimuli (DeLoache et al., 1979; Slater et al., 1984). Consistent with Gibson's theory (1971, 1979), these findings show that very young children can perceive similarities between pictures and their referents, with little or no prior pictorial experience. However, impressive perception, recognition, and discrimination abilities are not equivalent to understanding the symbolic function of pictures (DeLoache, 2003). Although children are immersed in visual representations from early infancy, and spend considerable time engaged in joint picture-book reading interactions with adults after the age of one (DeBaryshe, 1993; Ninio & Bruner, 1983), their early understanding of the meaning of two-dimensionality appears to be fragile. There are numerous accounts of young children displaying unusual behaviours towards pictures, seemingly confusing pictures and referents (Beilin & Pearlman, 1991; Werner & Kaplan, 1964). For instance, a 16-month-old trying to step into a picture of a shoe (Perner, 1991), and 9-month-olds hitting and grasping at images of objects (Murphy, 1978; Ninio & Bruner, 1978). When DeLoache and colleagues (1998) presented 9-month-old infants with highly realistic colour photographs of objects, all participants attempted to touch and grasp at least one of the pictures. This manual investigation of pictures suggests that infants sometimes fail to recognise that pictures are merely representations of their referent. This tendency to treat pictures as things of action rather than objects of contemplation (Werner & Kaplan, 1964) begins to decrease between 9- and 15-months, and referential behaviours (e.g. pointing and labelling) become more prominent (Carpenter et al., 1998). This could reflect an emerging appreciation that pictures are representations for things other than themselves (DeLoache et al., 1998).

Using pictures as a source of information about the world requires an awareness that pictorial symbols correspond to actual 3-D referents, even if the real-life referents are not present at the time of viewing. Indeed, despite the prevalence of pictures in children's early environments (DeBaryshe, 1993; Ninio & Bruner, 1983), pictures are rarely viewed in conjunction with their referents. Viewers must recognise that a picture of a 'cat' is an object and simultaneously represents an actual 'cat' in the real world. Thus, they must focus more predominantly on the intended representational meaning of a symbol, and less on its physical properties (Uttal et al., 2009). Experienced symbol users understand that pictures are referential and spontaneously generalise labels and information between symbols and their corresponding referents. For example, if an adult encountered a picture resembling an elephant, they would interpret the picture as a representation of ‘an elephant,’ and refer to the picture with the verbal label “elephant.” If someone else were to point to the tusks in the picture and say, “these are made of ivory”, the symbolically proficient adult would also extend this information about the picture to elephants in the real world.

An abundance of research evidence shows that toddlers are capable of utilising pictures as sources of information about the real world to successfully find hidden objects or imagine specific outcomes (DeLoache et al., 1997; Harris et al., 1997). However, as these studies often use familiar pictures that can easily be labelled, it is possible that young children may not fully appreciate the symbolic nature of pictures. Instead, their performance might reflect children’s reliance on linguistic labels to scaffold their developing understanding of pictorial symbols (Callaghan, 1999). To investigate this possibility, Callaghan (2000) presented 2.5- and 3-year-olds with a series of pictures and instructed them to choose the corresponding referents from pairs of objects. In conditions where linguistic scaffolding was not available, children would see two choice objects which shared the same basic label, such as two different breeds of dog. In conditions where linguistic scaffolding was available, children would see two choice objects with distinct labels, for instance a car and a bike. While the 3-year-olds consistently performed above chance in both conditions, the 2.5-year-olds only performed above chance when choice objects had different linguistic labels. These findings suggest that younger children are increasingly reliant on verbal labels when matching pictures and objects, compared to older children who can recognise the perceptual similarities between pictures and their corresponding referents. There is also evidence indicating that providing verbal labels for novel objects depicted in picture books, before identifying specific object properties, facilitates 21-month-old infants' transfer of this information to the corresponding 3-D referents (Khu et al., 2014).

To learn words from pictures, children must recognise that verbal labels paired with pictures represent independently existing objects. Empirical research illustrates that young neurotypical children spontaneously map labels to depicted referents and recognise referential relationships between words, pictures, and the objects they represent (Baldwin et al., 1996; Ganea et al., 2008; Hartley & Allen, 2014a, 2015a). For example, in one experiment examining this ability, neurotypical 18–24-month-olds were taught the name of an unfamiliar object (a whisk) using a black-and-white line drawing of the object (Preissler & Carey, 2004). Next, participants were prompted to identify the referent of the word 'whisk' from an array containing both the previously seen whisk picture and an unseen 3-D whisk. Despite being taught the word through the picture, both age groups consistently selected the real object or both the picture and the real object together, which suggests that they understood that the picture was not the sole referent of the word. However, in a more recent experiment, when 15–17-month-olds were taught the novel noun 'whisk' using pictures of two differently-coloured whisks (i.e. one orange, one purple), infants successfully extended the label 'whisk' to exemplars that differed in colour, and representational medium (i.e. from pictures to objects; Geraghty et al., 2014). This suggests that young children's ability to successfully map picture-referent relations is partly influenced by the variability of presented exemplars (Geraghty et al., 2014). Other influential factors identified by research include explicit verbal instructions (DeLoache, 1989), and the degree of iconicity between pictures and referents (DeLoache et al., 1991; Ganea et al., 2009).

Iconicity refers to the degree of perceptual resemblance between a symbol and its referent, with highly iconic symbols (e.g. colour photographs) categorised as "transparent", moderately iconic symbols (e.g. black-and-white line drawings) as "translucent", and symbols with minimal or no resemblance (e.g. written words) as "opaque" (Fuller, 1997). Increased perceptual similarity between a picture and its referent enhances the salience of the symbolic relationship, which increases the probability of the viewer successfully mapping the correspondence and drawing inferences between the two (DeLoache, 1995). Supporting evidence for this is provided by Ganea and colleagues (2008), who demonstrated that 15-month-olds accurately extend labels from highly iconic photographs to their corresponding objects, but not from less iconic cartoon pictures. When learning words from pictures, greater visual detail may contribute to the development of stronger representations of meaning during word-picture mapping, thereby supporting recognition of relationships between pictures and their referents when viewed independently (Ganea et al., 2008; Simcock & DeLoache, 2006). Indeed, when presented with realistic photographs in picture books, 13-month-old infants can make inductive references about non-obvious properties of corresponding 3-D referents and attempt to elicit those properties through specific actions depicted in the picture (Keates et al., 2014).

Overall, the studies reviewed in this section highlight the complex and multifaceted nature of children's development of symbolic understanding, which takes around five years to mature (DeLoache & Burns, 1994, DeLoache et al., 1998; Jolley, 2008; Rochat & Callaghan, 2005; Troseth & DeLoache, 1998). While infants demonstrate impressive perception, recognition, and discrimination abilities with pictures from a young age, their understanding of the symbolic function of pictures appears to be a gradual and fragile process. Early interactions with pictures often involve confusion between pictures and their referents, with young children displaying behaviours indicating a failure to recognise pictures as mere representations. However, as children mature, they gradually develop an appreciation of the referential relations that exist between words, pictures, and the objects they represent. Importantly, pictures serve as valuable tools for word learning, and this process may be influenced by iconicity. Specifically, highly iconic representations characterised by a close and faithful visual resemblance to real-world objects appears to facilitate young children's lexical acquisition (DeLoache et al., 1991; Ganea et al., 2008, 2009).

Understanding the symbolic function of pictures is a fundamental prerequisite for children to intentionally create graphic symbols (Callaghan, 1999, 2013). While picture comprehension skills encapsulate an individual's ability to decode and interpret symbolic meaning embedded within visual stimuli, picture production pertains to their capacity to create symbolic representations through drawing (Jolley & Rose, 2008). Drawing is an important cognitive tool, utilised by most cultures (Gombrich, 1995) to produce a diverse range of pictures, from simple sketches to elaborate illustrations (Fan et al., 2023). In early childhood, the ability to produce line drawings emerges (Jolley, 2010) and provides a rich and dynamic medium for children to explore and convey their perceptions, ideas, and experiences. Between the ages of one and two years, children engage in spontaneous mark making activities and produce seemingly random scribbles that lack specific form or intentionality (Cox, 1992). Imitation appears to play an important role in the development of children's picture production skills (Wilson & Wilson, 1977, 1982; Zimmerman, 1995). When children are asked to produce representational drawings of unfamiliar objects, the quality of their drawings notably improves when they observe an experimenter modelling how to draw the target objects beforehand, compared to trials without demonstration (Kirkham et al., 2013; Hartley et al., 2019). Over time, their scribbles start to become more controlled and resemble shapes (Golomb, 1981). According to Levin and Bus (2003), circles and lines are among the first drawing units observed in children's early drawing attempts, reflecting an emerging understanding of symbolic representation. At approximately three years old, children begin to produce simple representational drawings, using shapes to symbolise people and objects (Golomb, 1992; Winner, 1982).

Socio-cultural perspectives regard drawing as a non-verbal symbol system (Gardner, 1973) that emerges within the context of social communication. Like words and play, pictorial symbols serve as a mode of communication available to children, offering them a means to express themselves and engage with others (Callaghan, 1999; Gardner, 1973). This account underscores the interconnectedness of symbolic development and social interaction, highlighting the role of drawing as a vital tool for children to navigate and communicate within their social world. Young children eagerly share their drawings with other children and adults, who in turn, respond to these creations as if they were intentional and meaningful communications. This reciprocal exchange provides encouragement for the child, potentially reinforcing their burgeoning expressive abilities and facilitating further development in their symbolic communication skills (Callaghan, 1999; Vygotsky, 1978).

Theoretical Models of Symbolic Development

Extensive debate and discussion surrounding the ontogenetic development of symbolic understanding have given rise to numerous theoretical frameworks, which aim to explain how individuals acquire and learn to use symbols. Below, three prominent accounts are discussed, each offering a unique perspective on the extent to which language depends on, or is integrated with, other cognitive functions. These varying perspectives yield different hypotheses regarding the relationships between communicative domains (see Figure 1).

Socio-cultural accounts of symbol development place significant emphasis on the role of language, contending that it emerges as a precursor and mediates the subsequent development of other symbolic domains (Tomasello, 2003b; Vygotsky, 1978). According to this view, language acquisition arises from episodes of joint attention with other more experienced symbol users. Through these social interactions, infants refine their attentional behaviours (progressing from simple gaze following, to imitation, and pointing) while gradually developing their understanding of others as intentional agents (Tomasello et al., 1993). These important milestones facilitate the process of abstract mental representation, by enabling infants to consider and reflect on multiple perspectives (Tomasello, 1999). Thus, constructivists would argue that language, symbolic play, and pictures develop in a fixed sequence, with language emerging first – as a scaffolding base – and predicting other abilities over time.

Central to the social cultural account is the idea that symbol systems are cultural conventions acquired through social interactions with symbolically experienced partners (Callaghan et al., 2004, 2011, 2012). Neurotypical infants possess innate capacities to rapidly develop social-cognitive skills (e.g. intention reading and imitation), which enable them to learn the rules governing comprehension and usage of the specific symbol systems of the culture they are born into (Callaghan et al., 2011; Elmlinger et al., 2021; Tomasello et al., 1993). Engaging in communicative exchanges with symbol-minded others increase children's exposure to, and experience of, symbols across multiple domains (Callaghan & Rochat, 2008). Caregivers often initiate social exchanges and co-ordinate games such as peek-a-boo to captivate infants, evoke emotional responses, and establish social contingency (Stern, 1977; Watson, 1972). During such play episodes, infants can form visual schemas and orient their attention towards specific events which are scaffolded by the predictable, repeated speech signals and gestures from social partners (Greenfield, 1972). By observing the referential actions of others, inferring their communicative intentions, and reproducing the observed actions and intentions, children gradually build their understanding of symbols across various domains (Callaghan & Rochat, 2008). As they gain symbolic experience and realise that symbols are used to share meaning, children become more adept at inferring the *intended* meaning of the symbols generated by others and are increasingly able to actively participate in symbolic interactions, eventually producing their own symbols and initiating communicative exchanges (Rakoczy & Tomasello, 2006).

Domain-specific accounts envisage that the mind is composed of innate, specialised cognitive mechanisms, each dedicated to solving specific adaptive problems within distinct domains of functioning (Pinker, 1997). Evolutionary psychologists contend that each of these ‘modules’ has evolved through natural selection to address the recurring information-processing challenges faced by our evolutionary predecessors (Cosmides & Tooby, 1992). Since solutions to one problem would not have applied to others – for instance, strategies for navigating physical landscapes may not assist in forming social alliances – each adaptive problem would have favoured its own specialised cognitive adaptation. Proponents of this view assert that each separate module “should do one thing well” (Pinker, 1997, p. 91), implying that language is distinct from other cognitive systems (Chomsky, 1957; Fodor, 1983). Consequently, domain-specific theories of symbolic development would argue that language, symbolic play, and pictures develop independently, thus predicting no concurrent or longitudinal relationships between the three symbolic domains.

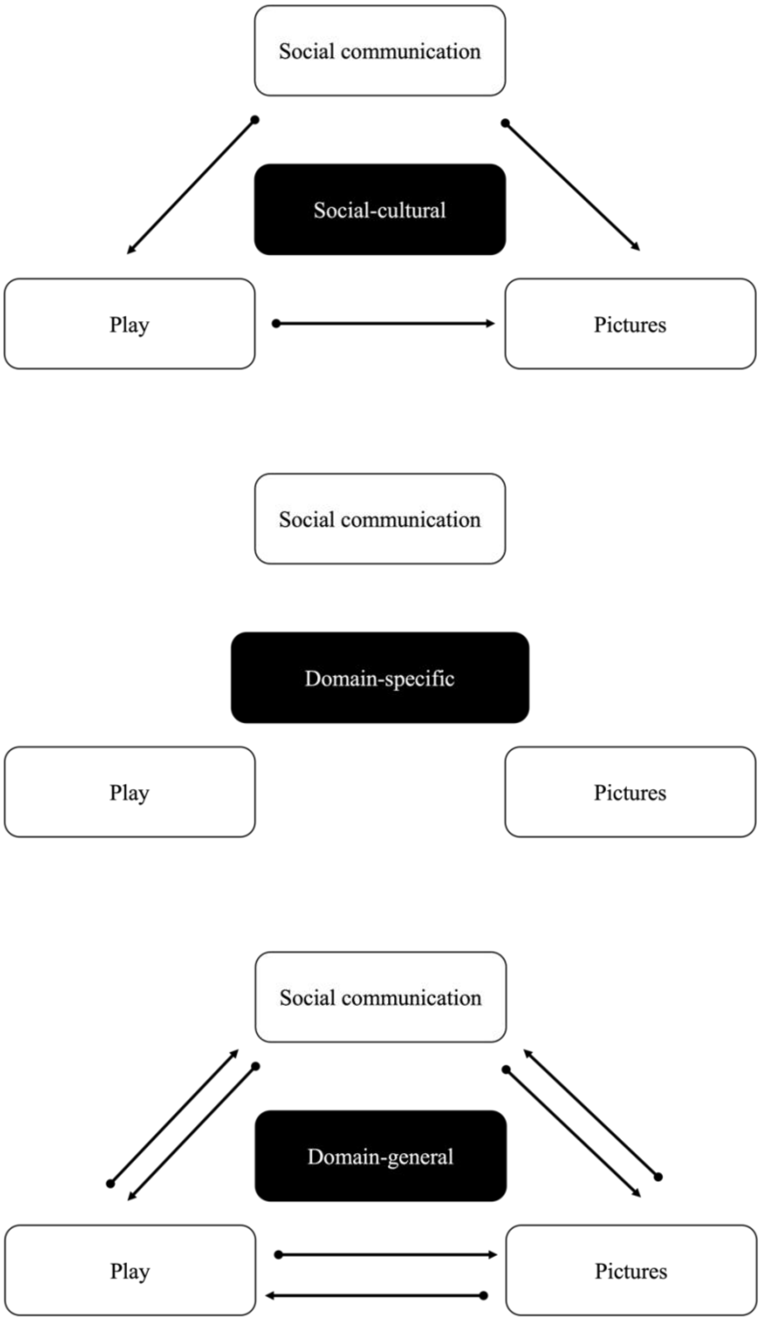
While there is some evidence suggesting domain-specific cognitive functioning in certain neurodiverse populations, such as autistic individuals (Baron-Cohen et al., 1985; Happé & Frith, 2006; Mottron et al., 2006; Plaisted et al., 1998), the overall picture is complex and does not provide strong support for strict domain-specific theories across all populations. Moreover, a key criticism of domain-specific theories is that while different adaptive challenges may indeed require unique responses, this does not necessarily mandate the presence of distinct, specialised cognitive modules (Buller, 2005). Instead, it is possible that the brain may employ a more general-purpose mechanism, or set of mechanisms, capable of flexible adaptation to various situations (Barrett, 2005). For instance, although tasks such as forming social alliances and navigating physical landscapes may appear distinct, they could both rely on a more generalised ability for complex problem-solving or social cognition. Thus, rather than requiring separate modules for each specific task, the brain might utilise a more integrated and adaptable cognitive system, as suggested by domain-general accounts of symbolic development.

Domain-general approaches posit that generalised cognitive mechanisms support learning across different domains in relative synchrony (Piaget, 1952). According to this view, language acquisition relies on specific cognitive prerequisites, such as understanding categorisation (Gopnik & Meltzoff, 1992). Fundamental achievements in abstract thought, such as representational insight (DeLoache, 2000), are regarded as shared internal processes that establish crucial foundations for expressing meaning in all symbolic systems, alongside other important skills, including vocal/motor control and visual memory (McCune, 2008). Consequently, domain-general accounts of symbolic understanding predict positive concurrent and longitudinal relationships between language, symbolic play, and pictures.

Piaget (1952) argues that the acquisition of a semiotic function around the age of two is facilitated by general mechanisms, such as assimilation and accommodation. Assimilation involves incorporating new experiences or information into existing mental schemas, while accommodation involves adapting and revising existing mental structures or schemas in response to new information or experiences that cannot be assimilated. These generalised mechanisms enable children to link 'signifiers' with the 'signified', and identify the meaning of symbols across different domains (Piaget & Inhelder, 1969). Supporting this perspective, numerous studies have identified significant concurrent and longitudinal relationships between symbolic play and language development. These connections are observed during the onset of both abilities, and persist in older children (Bates et al., 1979; Christie & Roskos, 2009; Doswell et al., 1994; Kirkham et al., 2013; Lewis et al., 2000; Quinn et al., 2018). However, beyond the claim that the associations between play and language reflect a common underlying representational system, there has been limited exploration into the comprehensive developmental accounts of their interrelationships.

Figure 1

Visualisation of interrelations between communicative domains, as predicted by social-cultural, domain-specific, and domain-general accounts of symbolic development



Note. Arrows represent direction of predictive relationships

In a rare exception, Callaghan and Rankin (2002) assessed children's comprehension and production of language, symbolic play, and pictorial symbols at monthly intervals from 28–36 months, and again at 42 months. To investigate whether language provides a scaffolding base for other symbol systems, the authors utilised variants of each measure that either enabled or prevented linguistic support. Across all three symbolic domains, significant positive correlations between comprehension measures were found, as well as the majority of production measures. However, as the unscaffolded measure of symbolic play production did not correlate with any of the linguistic or pictorial production measures, Callaghan and Rankin argue that children depended on their linguistic abilities to enhance their performance in the other symbolic domains. Overall, these longitudinal results indicate potential interconnectedness among language, pictures, and play in early development, supporting domain-general perspectives (Piaget, 1952). However, this study faced criticism due to its reliance on a limited sample size of only 16 participants and failure to account for the influence of non-verbal abilities on performance in each domain (Kirkham et al., 2013).

Building on this research, Kirkham and colleagues (2013) examined concurrent and longitudinal relationships between language, pictures, and play in a sample of 60 neurotypical 3–5-year-olds. In the first testing period, positive correlations were identified between the majority of measures across the three symbolic domains, indicating that children's linguistic, pictorial, and play skills are interrelated and develop in parallel between the ages of 3- and 4- years-old. This corroborates the findings of Callaghan and Rankin (2002) and provides further support for domain-general theories. However, when Kirkham and colleagues re-tested participants using the same experimental measures a year later (i.e. aged 4–5 years), they found that language *predicted*, but was not *predicted by*, graphic symbolism. Relationships between symbolic play and graphic symbolism approached statistical significance. These findings are broadly consistent with Vygotskian social-cultural theories, suggesting that linguistic symbols are mastered earlier in development and subsequently serve as a scaffolding base for pictorial domains, but perhaps not play. Evidence of a shift between the first and second time points indicates a possible plasticity of inter-domain relationships, suggesting that connections between language, pictures, and play might fluctuate throughout the course of development.

Further evidence of interrelations between symbolic domains in neurotypical 3–5-year-olds is provided by Hartley et al. (2019), who demonstrated that both receptive and expressive language abilities relate to picture comprehension, with only the former predicting significant variability. Overall, the existing research evidence indicates that although there may be a sequential progression of symbolic abilities, as proposed by constructivist perspectives, the relationships between these domains may be more complex and multifaceted, indicating potential bidirectional influences among them as in domain-general accounts.

Autism

The following sections will explore the development of non-linguistic symbolic domains in autism. While all autistic individuals share diagnosis-defining differences in communication and social interaction, and display restricted interests and repetitive behaviours (American Psychiatric Association, 2013), the presentation and severity of these features varies widely among individuals because ASD is a *spectrum* condition. For instance, in terms of cognitive functioning, the spectrum ranges from individuals with profound intellectual disability to those with exceptional intelligence (Grzadzinski et al., 2013). Similarly, language abilities are highly variable in ASD – some autistic individuals never develop functional spoken language, while others acquire verbal communication skills, but encounter difficulties in the pragmatic use of language (Ellis Weismer & Kover, 2015; Tager-Flusberg, 2003). Pragmatic language encompasses a wide range of social-linguistic skills that help individuals decide *when* to speak, *what* to say, and *how much* to say (Hymes, 1971; Prutting & Kirchner, 1987). Alongside difficulties, autistic individuals can also demonstrate strengths, including proficiency in visuo-spatial processing and memory (Plaisted et al., 1998; Shah & Frith, 1983). It is important to note that while communicative difficulties are pervasive across various symbolic domains in ASD, the interrelatedness of these modules remains largely unknown.

Social Communication in Autistic Development

Autistic individuals experience difficulties across multiple components of social communication. For instance, during social interactions, initiating and maintaining conversations, interpreting social cues (e.g. body language and facial expressions), and comprehending implicit rules of social engagement can be particularly challenging (Chevallier et al., 2012). Social cognition difficulties, including challenges with Theory of Mind – the ability to attribute mental states to oneself and others – and emotional understanding often manifest as difficulties inferring others' mental states, understanding sarcasm or irony, and predicting behaviour based on social cues (Baron-Cohen et al., 1985; Senju, 2012).

The development of social communication skills in ASD is characterised by distinctive challenges and delays compared to neurotypical children (Werner et al., 2000; Wetherby et al., 2004). Although most autistic children are not formally diagnosed until they are at least three years old, retrospective studies of families' home videos and prospective studies comparing infants at high- and low- inherited likelihood of developing ASD (i.e. younger siblings of children already diagnosed as autistic and those with no familial history of ASD respectively) provide evidence of clear differences in the early developmental trajectories of social and communicative behaviours. During early infancy, individuals subsequently diagnosed as autistic exhibit differences in eye contact (Volkmar et al., 2004;

Young et al., 2009), a reduced tendency to follow the gaze of others (Bradshaw et al., 2021; Klin et al. 2002), and infrequently orient to their name and other social stimuli (Dawson et al., 1998; Elsabbagh et al., 2013; Nadig et al., 2007; Osterling et al., 2002; Zwaigenbaum et al., 2005). Moreover, they may rarely attempt to communicate or establish joint attention with others through declarative pointing (Mitchell et al., 2006; Swinkels et al., 2006), potentially reflecting a reduced awareness that others' attention can be directed to specific aspects of one's environment. Between 12–14-months-old, stable and persistent social-communication difficulties are usually evident in this population (Landa et al., 2013; Pierce et al., 2019), with children encountering difficulties related to joint attention, imitation, reciprocity in social interactions, and understanding of non-verbal communication (D'Entremont & Yazbek, 2007; Gopnik, et al., 2001; Hamilton et al., 2007; Maestro et al., 2005; Osterling et al., 2002; Ozonoff, et al., 2011).

Several theories have been proposed to explain the social-cognitive difficulties observed in ASD. One of the most prominent accounts emphasises core difference in theory of mind (ToM), arguing that autistic individuals have difficulty understanding the perspective of others, which has downstream effects on social abilities (Baron-Cohen, 1995; Kimhi, 2014; Leslie, 1987). Although there is substantial research evidence demonstrating ToM differences in ASD (Baron-Cohen, 2001; Baron-Cohen et al., 1985; Happé & Frith, 1995; Leslie & Thaiss, 1992), critiques of this framework point out that the extent of difficulties may vary considerably among autistic individuals, and contextual factors such as language abilities and non-verbal intelligence may influence performance outcomes (Senju, 2012). Considering the predominant role of language in experimental tasks used to measure ToM, it is plausible that the performance of autistic participants is determined by language difficulties rather than differences in ToM itself (Tager-Flusberg, 2007).

Executive dysfunction theory proposes that differences in executive functioning contribute to social communication difficulties in autism (Hill, 2004; Jones et al., 2018). Executive function encompasses a range of advanced cognitive processes that include planning, initiation, shifting, monitoring, and inhibition of behaviours (Diamond, 2013). In ASD, difficulties with cognitive flexibility, as evidenced by limited ability to switch attention between tasks or perspectives (Landa et al., 1992), could impede autistic children's capacity to adapt to changing social situations. Additionally, differences in inhibitory control among autistic individuals may hinder their ability to suppress inappropriate behaviours or responses (Mosconi et al., 2009), potentially interfering with social interactions and communication. Furthermore, differences in working memory capacity in autistic children may impact their ability to retain and manipulate information during social interactions (Kenworthy et al., 2005). While executive dysfunction theory provides valuable insights into the cognitive mechanisms underlying social communication difficulties, it does not fully account for the heterogeneity observed in ASD. Some autistic individuals may demonstrate intact executive functions despite social communication difficulties, suggesting that other factors may also play a significant role (Geurts et al., 2014; Kenworthy et al., 2008).

The social motivation theory marks a shift in the focus of autism research, which has traditionally centred on cognitive differences (e.g. ToM difficulties or executive dysfunction) and relatively neglected motivational factors. According to this perspective, some autistic individuals may exhibit reduced motivation for social interaction due to diminished perception of social stimuli as inherently rewarding, leading to decreased engagement in social communication (Dawson et al., 2005). Initially proposed to elucidate different electrophysiological responses to facial cues and their potential implications for the development of face expertise in ASD (Dawson et al., 2005), this framework has since undergone refinement. Central to the social motivation theory is the proposition that differences in social motivation within ASD are partly attributable to disruptions in neural circuits implicated in processing social rewards, including regions such as the ventral striatum and prefrontal cortex (Chevallier et al., 2012; Failla et al., 2020). While this account provides valuable insights into the complex interplay between social motivation and social communication difficulties in ASD, it does not fully explain the heterogeneity of these abilities across the spectrum. Critics of the social motivation theory argue that reduced social motivation may be a secondary consequence of other core differences associated with ASD, such as difficulties in interpreting social cues or processing sensory information (Ronconi et al., 2016; Thye et al., 2018). Consequently, there remains a need for further research to disentangle the complex relationships between social motivation and other core features of autism, to elucidate our understanding of the mechanisms underlying social interaction difficulties in this population.

Ultimately, the delayed progress and variations in social communicative behaviours significantly impact autistic children's capacity to establish joint attention, and consequently reduce both the quantity and quality of social interactions with others (Delehanty & Wetherby, 2021; Iverson & Wozniak, 2016). These sub-optimal circumstances could potentially have cascading effects on the development of other symbolic domains. For example, diminished social motivation, a lack of early referential gestures, and imitation difficulties, could specifically hinder autistic children's ability to recognise and replicate the intentional actions of more symbolically competent social partners, and therefore limit their ability to make important inferences about the symbolic, representational function of pictures and play.

Language in Autistic Development

One of the hallmark features of ASD is delays in language development (Eigsti et al., 2011; Lord et al., 2006). This can manifest in various ways, including late onset of first words, limited vocabulary, difficulty with grammar and syntax, and challenges with pragmatic language (Ellis Weismer & Kover, 2015; Tager-Flusberg, 2003). While not mandatory for ASD diagnosis, receptive and expressive language difficulties are common co-occurring conditions, explicitly addressed in the DSM-5 diagnostic criteria (American Psychiatric Association, 2013; Brignell et al., 2018). This highlights the significant heterogeneity in language abilities within the autistic community, where some individuals may be non-verbal or minimally verbal, while others may demonstrate proficient language skills alongside social communication challenges (Anderson et al., 2007; Boucher, 2012; Norrelgen et al., 2015; Tager-Flusberg & Caronna, 2007).

While neurotypical children tend to produce their first words between 12–18-months-old, autistic children often demonstrate delays in reaching this developmental milestone (Lord et al., 2006; Tager-Flusberg et al., 2005). Some autistic children may not initiate spoken language until later in childhood, while others may display echolalia – repeating words or phrases – before developing spontaneous language (Thurm et al., 2007). Research conducted by Charman and colleagues (2003) highlights significant variations in the age at which autistic children produce their first spoken words, with some not initiating verbal communication until after the age of three years. Expressing thoughts and emotions can present difficulties for autistic individuals, which may hinder their ability to convey their needs effectively and engage in reciprocal conversations (Tager-Flusberg, 2007).

Compared to neurotypical peers, autistic toddlers generally exhibit reduced levels of both language production and comprehension (Hudry et al., 2010; Luyster et al., 2008; Tager-Flusberg et al., 2005). Additionally, they may not show an advantage for receptive over expressive communication skills (Hudry et al., 2014). Language comprehension difficulties in ASD encompass various challenges in understanding spoken language, following complex instructions, and processing linguistic nuances (Landa et al., 1992). Pragmatic language difficulties are also commonly observed in ASD, which can impact an individual's ability to understand and employ conversational rules such as turn-taking, maintaining topics, and interpreting non-literal language (Adams, 2002; Tager-Flusberg, 2007; Tager-Flusberg & Joseph, 2003).

Word learning difficulties in ASD are influenced by various factors beyond differences in language development. For instance, autistic individuals with more sophisticated cognitive functioning characterised by higher intelligence quotient (IQ), greater working memory capacity, and faster processing speed, tend to exhibit more proficient word-learning skills compared to those with more pronounced cognitive difficulties (Joseph et al., 2019). Moreover, research suggests that diminished responsiveness to social cues, such as eye gaze and pointing gestures, can impact vocabulary acquisition in ASD (Baron-Cohen et al., 1997). As fast mapping involves interpreting social cues to infer word meanings (McGregor et al., 2013), autistic children who experience challenges with social communication may struggle to utilise these cues effectively during word-learning tasks (Preissler & Carey, 2005). However, more contemporary research indicates that autistic children can effectively use social-communicative cues for referent selection (Bean Ellawadi & McGregor, 2016; Hani et al. 2013; Hartley et al., 2020; Luyster & Lord, 2009; McGregor et al., 2013). Additionally, autistic individuals can reliably use lexical heuristics, such as mutual exclusivity, to accurately identify the referents of unfamiliar words (Bedford et al., 2013; de Marchena et al., 2011; Hartley et al., 2019).

Furthermore, structured language interventions (Kasari et al., 2010), individualised teaching strategies (Dawson et al., 2010), and enriched learning environments (Gordon & Watson, 2015; Mundy, 2016) have been identified as influential factors in promoting language development and word acquisition among autistic individuals. Augmentative and alternative communication (AAC) methods can be beneficial for autistic individuals who experience significant language difficulties or remain non-verbal (Kagohara et al., 2013). AAC refers to any communicative system that is used to support or replace spoken communication (Schlosser & Wendt, 2008), ranging from low-tech options such as The Picture Exchange Communication System (PECS; Bondy & Frost, 1994; Frost & Bondy, 2002) to high-tech solutions involving speech-generating devices and tablet-based applications (Muharib & Alzrayer, 2017; Waddington et al., 2014). By providing alternative means of expression, AAC empowers autistic individuals to communicate effectively and engage more fully in various social and educational contexts. Continued research into AAC is crucial for refining interventions and improving outcomes for autistic individuals. Recognising the heterogeneity of abilities across language, cognition, and social communication in ASD is essential for developing individualised support and interventions.

Symbolic Play in Autistic Development

Autistic children demonstrate significant differences in play skills compared to neurotypical controls at equivalent developmental stages (Blanc et al., 2005; Holmes & Willoughby, 2005; Rutherford et al., 2007). Play episodes in ASD are generally characterised by more frequent engagement in functional play acts (e.g. simple, conventional actions on objects such as rolling a ball), reduced occurrence of symbolic play, and fewer instances of object substitutions (Campbell et al., 2018; Charman et al., 1998; Freeman & Kasari, 2013; Moerman et al., 2021). Notably, the absence or reduced frequency of using toys as agents, along with limited object substitutions during independent free play, serves as a diagnostic indicator in various autism assessment measures, including the Autism Diagnostic Observation Schedule-Second Edition (ADOS-2; Lord et al., 2012) and the Autism Diagnostic Interview-Revised (ADI-R; Rutter et al., 2003). These differences in symbolic play may limit opportunities for peer interaction and hinder the acquisition of appropriate play skills, and other critical developmental abilities (Boutot et al., 2005).

Several factors may contribute to the observed differences in symbolic play in ASD, including restricted, repetitive, and stereotyped behaviours, and challenges in understanding abstract concepts. Autistic children often exhibit intense, narrow interests in specific topics or objects, coupled with frequent engagement in self-stimulating or repetitive behaviours (e.g. hand flapping, spinning, and lining up objects; Gabriels et al., 2005; Leekam et al., 2011). Consequently, this may restrict the variety of their play experiences and reduce their motivation to engage in symbolic play which typically involves a broader range of objects and scenarios (Blanc et al., 2005; Holmes & Willoughby, 2005; Libby et al., 1998). Considering that aspects of symbolic play require language, cognitive flexibility (i.e. shifting to different thoughts or actions depending on situational demands; Monsell, 2003), and the capacity to understand and represent abstract concepts, delays and differences in these abilities among autistic individuals may hinder their engagement in symbolic play activities (Kelly et al., 2011). Strong correlations between play and language proficiency in autism have been identified, demonstrating that individuals with more developed language skills produce more symbolic play acts than those with less developed language skills (Sigman & Ruskin, 1999; Warreyn et al., 2005).

However, a lack of symbolic play in autism does not necessarily indicate a specific difficulty in symbolic abilities, but might instead reflect more general cognitive or social differences (Jarrold, 1993). Prior research has linked variability in symbolic play skills in ASD to factors such as non-verbal cognitive ability, expressive or receptive language (Sigman & Ruskin, 1999; Sigman & Ungerer, 1984; Warreyn et al., 2005; Whyte & Owens, 1989), and social development (Stahmer, 1995). However, most of these studies have utilised small samples and specifically focused on examining the impact of one or, at most, a few variables. To address these limitations, Stanley and Konstantareas (2007) examined the influences of multiple factors on symbolic play within a sample of 101 autistic children and found that play abilities were not uniquely tied to a single area of development. Non-verbal cognitive ability and language production were both significantly related to symbolic play, and social development was related to symbolic play, but only for participants with superior non-verbal cognitive abilities. These findings provide evidence of interconnectedness between various communicative domains in this group of autistic children, suggesting that delays and differences in one area may influence performance outcomes in other areas.

Although there is evidence of significant correlations between children's play, language, and social-cognitive abilities in ASD (Thiemann-Bourque et al., 2012; Toth et al., 2006), the precise nature of these relationships is not clear. It is plausible that the association between play and language in autism is influenced by factors such as modelling and explicit instruction, which have been shown to enhance the likelihood of autistic individuals engaging in pretend play (Jarrold, 2003; Lydon et al., 2011; MacDonald & Sacramone, 2009; Thomas & Smith, 2004). This suggests that the relationship between play and language could be mediated through social support provided by more symbolically experienced social partners (Lewis, 2003). Understanding the complex interplay of these factors is essential for advancing theoretical understanding and developing targeted interventions to support the development of symbolic play skills in autistic children.

Pictorial Comprehension and Production in Autistic Development

Despite widespread use of picture-based interventions to support minimally verbal autistic individuals, there is a notable lack of research examining how this population perceive and comprehend pictures. Existing research has explored some of the challenges faced by autistic individuals in understanding symbolic word-picture-object relations. For instance, Preissler (2008) taught minimally verbal autistic children the word "whisk" in conjunction with a black-and-white line drawing depicting a whisk. In contrast to the neurotypical participants of Preissler and Carey's (2004) 'whisk' experiment, the majority of autistic children demonstrated a limited conceptualisation of the word “whisk”, associating it solely with the accompanying picture and failing to extend the label to the represented object (Preissler, 2008). These findings are particularly concerning as it is common for autistic individuals to be taught the names for 3-D objects via labelling their 2-D counterparts via AAC interventions (Bondy & Frost, 1994; Kasari et al., 2014). However, since Preissler (2008) utilised moderately iconic “translucent” symbols (Fuller, 1997), there is a chance that autistic participants were influenced by the iconicity of the pictorial stimuli. To test this possibility, Hartley and Allen (2015a) investigated how autistic children extend labels from pictures with varying degrees of iconicity. Participants were most accurate in extending words to objects when taught using highly iconic “transparent” colour photographs, and were more inclined to extend names to objects depicted in colour pictures than non-colour pictures. These findings emphasise the fundamental role of iconicity in shaping the use and understanding of pictures among autistic individuals. Further research exploring the nuances of iconicity and its implications for symbolic understanding in ASD is warranted to advance theoretical understanding and inform evidence-based practices in the field.

Prior research examining picture production abilities in ASD indicates equivalent performance with neurotypical controls, matched on mental age or language comprehension skills, when representing objects, basic concepts, and emotions (Hartley et al., 2019; Jolley et al., 2013; McCarthy et al., 2018). However, autistic children tend to produce fewer imaginative drawings compared to their neurotypical peers (Low et al., 2009). In addition, they also encounter challenges when attempting to spontaneously depict imaginary scenarios, as evidenced by their difficulties in responding to specific prompts such as ‘draw a man with two heads’ or ‘draw a door in the roof of a house’ (Craig et al., 2001; Leevers & Harris, 1998). Interestingly, when provided with pre-drawn templates to complete, autistic children exhibit comparable abilities to neurotypical children and those with learning difficulties in depicting impossible entities (Allen, 2009). As mental age and imaginative drawing abilities were only related in the ASD group, Allen (2009) suggest that language comprehension skills may scaffold imaginative drawing processes in the autistic population. If this is the case, individuals with more severe receptive language abilities difficulties may also encounter difficulties learning to draw.

In an experiment investigating picture production abilities in linguistically delayed autistic children and neurotypical controls matched on both receptive and expressive language skills, participants were asked to draw a selection of unfamiliar objects under conditions of varying difficulty (Hartley et al., 2019). During the modelled trials, participants observed the experimenter demonstrating how to draw each unfamiliar item before creating their own representational drawing. Conversely, in the unmodelled trials, participants received no demonstrations, making this condition the more challenging of the two. Both groups demonstrated comparable performance, achieving greater accuracy in modelled trials compared to unmodelled trials. This suggests that autistic children's object drawing abilities are intact when expectations align with their linguistic capacities, hinting at a potential link between language and picture production skills. This could potentially be driven by structural and developmental similarities that exist between these two symbolic systems (Cohn, 2015). Both drawing and language are important representational systems used by humans (Gombrich, 1995; Fan et al., 2023), requiring access to schemas that are stored in memory, which can be combined to generate an infinite array of novel expressions (Cohn, 2015). While the latter utilises systematic sounds to convey thoughts and concepts, the former offers a visual means of expressing ideas. If language indeed plays a mediating role in children's ability to produce representational drawings, then early difficulties in the pictorial domain may diminish as their expressive language skills develop.

Theoretical Models of Symbolic Development

As social communication and language abilities are intimately related in early neurotypical development and may provide a vital scaffold for play and pictorial domains (Vygotksy, 1978), delays and differences in these domains – such as those commonly observed in ASD – could have critical downstream consequences for non-linguistic symbolic understanding. Diagnosis-defining differences in social-motivation and social-cognition in ASD (American Psychiatric Association, 2013; Carpenter et al., 2001; Chevallier et al., 2012) could prompt alternative routes for learning. For instance, the development of play and pictorial understanding despite language and social communication difficulties would suggest that these symbolic domains operate relatively independently in autism. This pattern of results would align with domain-specific accounts of symbolic development (Chomsky, 1957; Pinker, 1997). Alternatively, concurrent interrelationships between social communication, pictures, and play would indicate that these modules are interdependent and potentially underpinned by shared factors. Specific unidirectional relationships (i.e. social communication predicting pictures and play, but not the reverse) would provide support for social-cultural perspectives (Vygotksy, 1978), while bidirectional relationships between the three modules would align more closely with domain-general accounts (Piaget, 1952).

Determining which theoretical account best represents the interrelations between symbolic and social-cognitive domains in ASD is challenging due to a paucity of previous evidence. Existing studies predominantly focus on examining the influence of a limited set of variables, overlooking the broader context of symbolic development. Moreover, these studies often fail to acknowledge that infants' comprehension skills generally surpass their productive skills in every symbolic domain (Callaghan, 1999). To our knowledge, there is currently only one existing study that has examined concurrent interrelationships across multiple symbolic domains in the autistic population. As previously discussed, Stanley and

Konstantareas (2007) provide evidence of interconnectedness between various communicative domains in a large sample of autistic children, suggesting that delays and differences in one area may influence performance outcomes in other areas. However, the absence of a language-matched neurotypical control group in this study makes it difficult to determine whether the observed patterns of interrelationships between symbolic domains are specific to autism or reflect more general developmental processes. Furthermore, by neglecting to examine pictorial domains, this study overlooks a significant aspect of symbolic functioning in ASD, precluding a comprehensive investigation of the interconnectedness between social communication, play, and pictures.

Factors Contributing to Within- and Between- Population Variability

Exploring the concurrent interrelationships across social communication, pictures, and play, while considering various individual differences as moderating factors, could reveal significant within- and between-population variability in neurotypical and autistic children. Several factors may contribute to these differences, which could be crucial for understanding how children use and comprehend multiple non-linguistic symbolic domains and for identifying individual differences within these populations. Gaining insight into these factors is essential for accurately interpreting research findings and developing effective interventions. By accounting for differences in chronological age, autistic traits, non-verbal intelligence, language, and fine motor skills, researchers and practitioners can better support the symbolic understanding of both neurotypical and autistic children.

Chronological Age

Chronological age provides context for interpreting cognitive, linguistic, and symbolic abilities, ensuring that observed differences in skills are not mistakenly attributed to developmental variations. Incorporating chronological age as a measure of individual difference ensures that variations in language, social communication, pictorial, and play skills are appropriately contextualised within the developmental trajectory (Thomas et al., 2009). For example, younger children might display different profiles in symbolic play and drawing due to their developmental stage and emerging cognitive capacities (Zelazo & Frye, 1997). By accounting for chronological age, researchers can more accurately isolate age-related processes and enhance the reliability and relevance of findings across both neurotypical and autistic populations (Jarrold & Brock, 2004).

Autistic Traits

Measuring autistic traits is essential for a nuanced understanding of how autism influences cognitive, linguistic, and symbolic abilities. Traits such as social communication difficulties and restricted or repetitive behaviours can significantly impact both linguistic and non-linguistic symbol use and comprehension (Lord et al., 2006). By accounting for these traits, studies can more accurately determine how specific characteristics influence language and symbolic skills, differentiating between the effects of autism-related behaviours and other developmental factors. This precision enhances the reliability and applicability of findings, and has important implications for targeted interventions (Dawson et al., 2010; Kasari et al., 2006; Landa et al., 2011).

Non-verbal Intelligence

Non-verbal intelligence, encompassing skills such as problem-solving, spatial reasoning, and pattern recognition, is critical for cognitive processing in tasks that do not rely on language. For example, children with higher non-verbal intelligence might better grasp the symbolic nature of pictures or engage in complex play requiring spatial understanding (Smith & Jones, 2011). In autistic individuals, higher non-verbal intelligence is associated with more sophisticated social interaction and understanding, which may directly enhance play skills (Joseph et al., 2002). Measuring non-verbal intelligence enables control for its influence on symbolic representation, ensuring that differences observed in symbolic understanding reflect genuine variations in symbolic domain processing.

Language

To comprehensively understand language development in neurotypical and autistic participants, both receptive and expressive language skills should be measured. This approach facilitates the identification and comparison of language profiles across groups, highlighting discrepancies that might not be apparent when assessing only one aspect of language. Neurotypical children usually display a receptive-over-expressive language advantage, meaning they generally understand more language than they can produce (Fenson et al., 1994). However, this pattern is not consistently observed in autistic children, who often show uneven language development (Hudry et al., 2010). In such cases, expressive language skills might match or even exceed receptive skills (Davidson & Ellis Weismer, 2017; Haebig & Sterling, 2017; Reinhartsen et al., 2019).

Several factors may contribute to this discrepancy (Hudry et al., 2014; Kwok et al., 2015). Autistic children may demonstrate a heightened focus on specific words or phrases, a phenomenon known as hyperlexia, which could result in strong expressive language abilities in certain contexts, while their broader understanding of language nuances might lag (Nation et al., 2006). Additionally, challenges with pragmatic language – understanding the social use of language – may limit receptive skills even as expressive skills develop through rote learning or echolalia (Tager-Flusberg, 2003). Difficulties with theory of mind can further affect language comprehension, making it challenging for autistic children to grasp contextual meanings (Baron-Cohen, 2001). Consequently, while autistic children may appear fluent in certain scripted or predictable language contexts, their understanding of nuanced or socially complex language might be less developed. These factors illustrate why the typical receptive-over-expressive language advantage may not apply in autism, and emphasise the importance of measuring both language production and language comprehension to gain a more complete understanding of symbolic development.

Fine Motor Skills

Assessing fine motor skills enables identification of potential motor difficulties that could confound the interpretation of participants' drawing abilities. Autistic children often exhibit differences or delays in fine motor skills compared to neurotypical children, impacting their ability to perform tasks that require precise hand movements, such as drawing, writing, or manipulating small objects (Jasmin et al., 2009; Lloyd et al., 2013). These difficulties can emerge early in development and persist into adolescence, potentially influencing broader cognitive and social skills (Fournier et al., 2010). Fine motor dexterity is crucial for manipulating objects and tools, affecting both the complexity of symbolic play and the quality of representational drawings (Case-Smith, 2002). Furthermore, fine motor skills are linked to overall cognitive and developmental functioning, which impacts social engagement and interaction (O'Hara et al., 2019). For example, effective use of gestures, such as pointing, is foundational for joint attention and communication. Children with fine motor difficulties may struggle with using gestures effectively, potentially affecting their ability to communicate and interact with others (Iverson, 2010). Therefore, assessing fine motor skills is vital for accurately interpreting differences in symbolic task performance and understanding their role in developmental domains.

Theoretical perspectives offer varied explanations for the relationship between fine motor skills and symbolic understanding. Domain-general theories propose a broad and direct impact, suggesting that enhanced fine motor skills improve a wide range of cognitive functions, including symbolic play and representational drawing. In this view, more developed fine motor skills enhance children's ability to perform detailed and controlled movements, which translates into more complex and accurate pictorial representations and play activities (Cameron et al., 2012). This account suggests that as fine motor skills develop, there is a concomitant improvement in pictorial and play abilities without necessarily involving a distinct symbolic developmental process. In contrast, sociocultural accounts highlight an indirect influence, where fine motor skills support symbolic development through interactions with cultural tools and social contexts. This framework argues that fine motor skills are crucial for early symbolic understanding because they enable children to manipulate objects in ways that foster cognitive and representational thinking (Rogoff, 2003; Vygotsky, 1978). As children develop the motor coordination required to stack blocks or draw shapes, they also begin to understand how these actions can symbolise other objects or abstract ideas (DeLoache, 1995).

Bridging these two perspectives, embodied cognition theory offers a unifying explanation, suggesting that cognitive processes are grounded in physical interactions with the environment. This theory integrates both the direct, domain-general view and the sociocultural perspective by positing that the experience of manipulating objects directly fosters more sophisticated symbolic play and drawing (Dinehart & Manfra, 2013; Glenberg, 2010; Wilson, 2002). From this perspective, the physical act of manipulating objects directly enhances cognitive development, supporting both broad symbolic abilities and culturally mediated understanding. Embodied cognition thus provides a comprehensive explanation that links motor skills to symbolic understanding through both direct physical interaction and cultural engagement (Barsalou, 2008).

Domain-specific theories, on the other hand, focus on the direct impact of fine motor skills on particular tasks, suggesting that these skills develop independently of broader cognitive processes such as language acquisition or problem-solving (Pinker, 1997). Improvements in fine motor skills are tailored to specific activities, such as drawing or block construction, where the motor coordination required for these tasks enhances performance in those areas (Piek et al., 2008). For instance, the precise motor skills involved in grasping and manipulating drawing tools might lead to more detailed and accurate drawings, while the coordination needed to assemble complex block structures could support more sophisticated play activities. This perspective posits that fine motor skills influence pictorial and play abilities through distinct mechanisms, reflecting specialised developmental pathways rather than general cognitive improvements.

Neurotypical children appear to benefit from both direct and mediated pathways in symbolic understanding (Smith & Jones, 2011). As discussed earlier in this chapter, neurotypical children frequently engage in activities that integrate motor and symbolic development, such as drawing, pretend play, and interactive games (Iverson, 2010). As their fine motor skills become increasingly refined, their ability to create detailed pictorial representations and engage in more complex play usually advances in parallel, reflecting both direct improvements and gains mediated through enhanced symbolic understanding (Cameron et al., 2012; Smith & Thelen, 2003). In contrast, autistic children's development of symbolic understanding may be more strongly tied to their physical interactions with objects rather than social experiences. Given their unique sensory processing styles and different approaches to social engagement, autistic children may experience symbolic development in a way that is more "socially disembodied" (Dawson et al., 1998; Klin et al., 2003). Fine motor skills may more directly influence their symbolic development, as their ability to manipulate objects and engage in solitary play becomes the primary mechanism through which they understand symbols and representations (Marr et al., 2001). For example, their skills in drawing and object manipulation may foster symbolic understanding rooted in their physical experiences, rather than through imitation or social interaction. Consequently, the development of pictorial and play abilities in autistic children may reflect a stronger, more direct link between fine motor skills and symbolic understanding (Jasmin et al., 2009;

Ketcheson et al., 2017). Understanding these nuanced relationships is crucial for developing targeted interventions that cater to the specific developmental profiles of neurotypical and autistic children (Fournier et al., 2010).

Thesis Objectives

Throughout the preceding review, several gaps in the current literature have been identified. First, a significant limitation of current research is the lack of comprehensive investigation into the concurrent interrelationships among social communication, play, and pictures, alongside consideration of various moderating factors as individual differences. Furthermore, many studies overlook the importance of measuring receptive and expressive abilities in each domain, which further prevents comprehensive profiling of children's symbolic abilities. These issues are applicable to both neurotypical and autistic populations and require urgent research attention. Generating this knowledge will advance theoretical understanding of inter-domain relationships in neurotypical and autistic children. This, in turn, would provide opportunities to subsequently examine whether raw performance of language-matched samples drawn from both populations differ in the three non-linguistic symbolic domains, and determine whether relationships between domains differ in terms of their presence, direction, and magnitude across populations. Since many autistic children who struggle with language are taught to communicate using picture-based AAC interventions, understanding factors that influence these processes is crucial for developing educational and clinical interventions. Thus, research should also explore how children acquire symbolic information across multiple symbolic domains, such as learning novel words from pictures.

This thesis explores inter-domain relationships across social communication, play, and pictures simultaneously, with the addition of other moderating factors as individual differences in both neurotypical and autistic populations. The first two experimental studies investigate how variability in language, chronological age, fine motor skills, and non-verbal intelligence predict children's abilities in the domains of pictures, play, and social communication, and model concurrent interrelations between these non-linguistic symbolic domains in neurotypical 2–5-year-olds (Chapter 2) and 4–11-year-old autistic children (Chapter 3). The third experiment explores whether there are differences in the existence and nature of predictive relationships between symbolic domains in autistic and neurotypical children matched on language comprehension (Chapter 4). Chapter 5 has an applied focus and investigates how ASD influences children's ability to learn words that vary in iconicity (e.g. colour photographs vs. black-and-white cartoons).

Chapter 2: How does variability in language, and other individual differences, predict symbolic and social-cognitive abilities in neurotypical children?

Chapter Introduction

The current research literature has predominantly focussed on examining social communication, play, and pictures in isolation, or exploring connections between two symbolic domains at a time, rather than considering the complex interactions that can occur across multiple domains. This chapter presents a study that addresses this limitation, by investigating concurrent inter-domain relationships between social communication, play, and pictures and other individual differences, including language abilities, non-verbal intelligence, and fine motor skills, in neurotypical 2–5-year-olds. Understanding the predictive relationships between symbolic abilities and individual differences, and how symbolic domains concurrently interrelate, could potentially inform the design and delivery of early education practices.

Author Contribution: *Cheriece Carter*: design, data collection, analysis, writing, review. *Calum Hartley*: design, analysis, review.

Abstract

Becoming symbol-minded is an important hallmark of human cognition that enables effective communication and full participation in society. While some developmental theories propose that language acquisition is mediated by children's social communication abilities, and scaffolds subsequent learning of other non-linguistic symbol systems (e.g. pictures and play), the existing research literature lacks a comprehensive examination of concurrent inter-domain relationships across multiple symbolic domains. Therefore, the current study modelled how variability in language, and other individual differences, predicted children's abilities in social communication, play, and pictures, and modelled relationships between these domains. Neurotypical children aged 2–5 years old completed a battery of standardised assessments and experimental tasks. Our results identified reciprocal relationships between all three domains. These findings suggest that pictorial, play, and social communication domains may be underpinned by shared factors, and demonstrate that interactions with more symbolically experienced partners scaffold children's symbolic abilities across domains.

Introduction

Symbolic communication is at the core of human cognition (Deacon, 1997). Children must learn to use and understand a wide repertoire of symbols, including gestures, pictures, and words, in order to communicate effectively (Callaghan et al., 2011; DeLoache, 2004; Klin et al., 2002). Language – arguably the most crucial symbol system – typically emerges after the development of various attention monitoring behaviours between 9–12 months of age (Carpenter et al., 1998; Tomasello, 2003b). Once acquired, language may then mediate the development of symbolic play and pictorial understanding (Kirkham et al., 2013; Vygotsky, 1978). However, a significant limitation of the existing literature is that no study to date has comprehensively investigated inter-domain relationships across social communication, language, play, and pictures. To address this gap, the aims of this study are twofold: (1) investigate how variability in language, and other individual differences, predicts neurotypical 2–5-year-olds' abilities in the domains of pictures, play, and social communication and (2) model concurrent interrelations between these symbolic domains.

During the first year of life, infants develop a repertoire of social-cognitive skills including imitation, gaze following, pointing to direct the attention of others, and joint attention (Bates et al., 1979; Carpenter et al., 1998, 2002; Meltzoff, 1988). These skills involve the coordination of attention between two individuals and an event/object of mutual interest and enable pre-verbal infants to recognise others as intentional agents, communicate with them, and begin to link words with referents (Baldwin, 1995). Social communication skills are therefore considered to scaffold children's early language development (Bruner, 1983; Tomasello & Farrar, 1986). Indeed, children's joint attention skills predict early language acquisition and later language ability (Carpenter et al., 1998; Morales et al., 1998, 2000; Mundy & Gomes, 1998). Social communication skills are also implicated in the development of non-linguistic symbol systems (Callaghan et al., 2011). Infants' earliest referential actions on pictures are imitated from adults (Callaghan et al., 2004) and, by 2–3 years, children utilise intention reading skills when relating pictures to the world (Hartley & Allen, 2014; Salsa & de Mendoza, 2007). As symbol systems are cultural conventions that must be acquired from others, previous research has examined whether children's ability to use and understand pictorial symbols is mediated by social exchanges with more proficient symbol users (Callaghan et al., 2011, 2012; Callaghan & Rankin, 2002). In an experiment conducted by Callaghan and colleagues (2004), 6–18-month-old infants witnessed an adult modelling one of two stances towards pictures and referent objects. In the contemplative condition, adults held up stimuli, pointed to it, and looked between the infant and the item. In the manipulative condition, adults moved and shook stimuli in front of the infant. They found that infants aged 12+ months reliably imitated modelled actions towards pictures, regardless of appropriateness, but not for objects. These findings indicate that children's understanding of the referential nature of pictorial symbols is mediated by the behaviour of symbolically experienced adults.

While children typically produce their first words around 12–18 months (Tager-Flusberg et al., 2009; Zubrick et al., 2007), their ability to understand and produce pictorial symbols generally emerges much later at approximately 3 years old (Callaghan, 1999; Nelson, 2007). Although 2.5-year-olds can successfully use pictures to solve memory search and imaginary outcome tasks (DeLoache et al., 1997; Harris et al., 1997), these studies usually employ pictures of familiar, easily labelled objects, making it difficult to establish whether children at this age truly understand the symbolic function of pictures, or if they are using language labels to scaffold an emerging understanding of graphic symbols (Callaghan, 1999). To address this potential scaffolding role of language, Callaghan (2000) showed 2.5- and 3-year-olds a series of pictures and instructed them to choose the corresponding referents from pairs of objects. Although verbal mediation of children's picture-object matching was possible when choice objects had different labels (e.g. a cat and a dog), linguistic scaffolding was not possible when choice objects shared the same basic label (e.g. two different cats). While the 3-year-olds performed above chance regardless of linguistic scaffolding, the 2.5-year-olds only performed above chance when choice objects had distinct labels. This suggests that children under 3 years are more reliant on verbal labels when matching pictures and objects compared to older children, who can discern the perceptual similarities between graphic symbols and their referents. As young children in Western societies are exposed to a range of visual representations, particularly during joint picture-book reading interactions with caregivers where pictures are often explicitly labelled (Ganea et al., 2008; Ninio & Bruner, 1978), it is possible that language directly supports children's early use and understanding of graphic symbols.

Picture comprehension skills involve decoding and interpreting symbolic meaning embedded within visual stimuli, whereas picture production refers to the ability to create symbolic representations through drawing (Jolley & Rose, 2008). In early childhood, typically between the ages of one and two, children begin to explore drawing as a form of expression. Initially, these drawing attempts often result in seemingly random marks devoid of specific form or intention (Cox, 1992). However, over time, children's scribbles begin to resemble shapes, with circles and lines being among the first recognisable elements (Levin & Bus, 2003). This progression suggests a developing understanding of symbolic representation (Golomb, 1981). Around the age of three, children start to create simple representational drawings, using shapes to depict people and objects (Golomb, 1992; Winner, 1982). Notably, when children attempt to produce representational drawings of unfamiliar objects, their drawing quality significantly improves when provided with explicit physical demonstrations provided by an adult, compared to fully independent attempts (Hartley et al., 2019; Kirkham et al., 2013). This highlights the important influence of imitation on shaping children's picture production abilities (Wilson & Wilson, 1977, 1982; Zimmerman, 1995).

The association between drawing and language in early childhood, as well as the potential influence of domain-general aspects of cognition, is an area of study that remains relatively unexplored and warrants further investigation (Panesi & Morra, 2018, 2022**)**. The literature presents different perspectives on the relationship between these two symbolic domains. According to social-cultural accounts, drawing is influenced by language (Golomb, 1992; Vygotsky, 1978). Just as children utilise verbal labels to scaffold their performance in picture comprehension tasks (Callaghan, 2000), their use of words to identify objects and/or engage in verbal planning may also influence their transition from scribbling to drawing recognisable shapes (Golomb, 1992; Toomela, 2002). In contrast, nativist domain-specific perspectives suggest that drawing and language develop independently, due to the distinct processing of visual and verbal information along separate, specialised cognitive channels (Chomsky, 1964; Paivio, 1971). Domain-general theories, on the other hand, regard both language and drawing as related signifying systems which arise from a shared symbolic function (Piaget & Inhelder, 1969). According to Piaget (1952), the acquisition of this symbolic function in the second year of life relies on general mechanisms – 'assimilation' and 'accommodation' – which enable children to connect symbols and referents across different symbolic domains.

Between 18–30 months old, children's play activities typically involve object-substitution pretence (e.g. using a banana as a telephone or a stick as a sword; Bergen, 2002; Lillard, 2017; McCune, 1995). Between 3–5 years old, more complex symbolic play activities emerge that necessitate use of imagination, such as pretending with invisible objects (Lillard et al., 2013; Singer & Singer, 1990). In a sample of 225 children aged 3–6 years old, Holmes et al. (2015) found that individuals with lower receptive language scores engaged more frequently in parallel play (e.g. playing independently alongside others) compared to children with higher receptive language scores who participated more frequently in complex social play (e.g. cooperative social pretend play). These findings align with previous research, indicating that receptive and expressive vocabulary are concurrently related to symbolic play skills in children aged 1–6 years (Christie & Roskos, 2009; Doswell et al., 1994; Lewis et al., 2000; Quinn et al., 2018).

Although there is evidence to suggest that children's pretend play, language, and symbolic understanding are strongly related (Lillard et al., 2013; Orr & Geva, 2015; Quinn et al., 2018; Smith & Jones, 2011; Zlatev & McCune, 2014), it is difficult to disentangle these close correlations, because very few studies present evidence for predictive relationships (Russ & Wallace, 2013). This is further complicated by the fact that language and pretend play mutually "depend on the capacity for symbolic understanding" (Pleyer, 2020, p. 349), meaning children must recognise that a specific entity (e.g. a word or an object) can be substituted to symbolically represent something else or be used as though it were something else (Fein, 1987). Furthermore, pretend play is an inherently social activity that provides opportunities for children to develop perspective-taking skills and engage in co-operative activities with others with shared intentions (Rakoczy, 2006; Vygotsky, 1978), and social-cognitive abilities are strongly implicated in language development (Tomasello, 2008). Nevertheless, it has been argued that complex pretend play provides meaningful scaffolding opportunities for developing important linguistic and social-cognitive skills that directly contribute to children's use and understanding of language (Christie & Roskos, 2009; Langley et al., 2019; Nell et al., 2013, Quinn & Kidd, 2019; Trawick-Smith, 1998). This could be driven by the language used during play with more competent play partners (Lillard et al., 2010) or outside of play when children talk about pretence with others (Bergen, 2002).

To date, very few studies have investigated interrelationships between multiple symbolic domains. In their longitudinal study, Callaghan and Rankin (2002) assessed children's comprehension and production of language, symbolic play, and graphic symbols in a sample of 16 neurotypical children aged 28–42 months. They reported strong correlations between language comprehension and picture comprehension, language production and picture production, and play comprehension and picture comprehension. Evidence of interrelationships across all three domains demonstrate potential interconnectedness among language, pictures, and play in early development, thus providing support for domain-general perspectives (Piaget, 1952). Kirkham et al. (2013) extended this study by examining relationships between these three symbolic domains in a larger sample of 60 neurotypical children aged 4-5 years old, and found that language *predicted*, but was not *predicted by*, graphic symbolism. Relationships between symbolic play and graphic symbolism approached statistical significance. These findings are consistent with Vygotskian social-cultural theories, suggesting that linguistic symbols are mastered earlier in development and subsequently serve as a scaffolding base for other symbolic domains (e.g. pictures). A recent study conducted by Hartley et al. (2019) demonstrated that in neurotypical children aged 3–5 years, both language comprehension and language production contribute to picture comprehension, with only the former predicting significant variability. This provides further evidence of interrelations between development in linguistic and pictorial domains.

A crucial limitation of the extant literature is that no study to date has comprehensively investigated inter-domain relationships across social communication, language, play, and pictures simultaneously, with the addition of other moderating factors (e.g. fine motor skills) as individual differences. Furthermore, most studies fail to acknowledge that young infants' comprehension skills outweigh their productive skills in every symbolic domain (Callaghan, 1999). Thus, measures of both receptive *and* expressive abilities in each domain are required to comprehensively profile a child's symbolic ability. Addressing these important issues is necessary to advance theoretical understanding of the concurrent relationships between symbolic abilities and individual differences, establish how symbolic domains concurrently interrelate, and potentially inform the design and delivery of early education practices. Therefore, the objectives of the present study were to model: i) concurrent relationships between children's language abilities, other individual differences (e.g. chronological age, fine motor skills, non-verbal intelligence) and skills across the domains of pictures, play, and social communication in neurotypical children aged 2–5 years old and ii) concurrent interrelations between the three non-linguistic symbolic domains.

Picture comprehension was assessed via a picture-object matching task based on the procedure devised by Callaghan (2000), which manipulated whether children could utilise verbal labelling to scaffold their performance. Picture production was tested using an object-drawing task based on Kirkham et al. (2013), which required children to draw pictures of unfamiliar target objects with, and without, adult modelling. Symbolic play was assessed via a series of tasks adapted from the Autism Diagnostic Observation Schedule Version 2 (ADOS-2; Lord et al., 2012), which enabled probing of children's spontaneous, independent play abilities during a free play session, as well as functional and symbolic play skills during the context of a familiar social routine led by an adult (i.e. a birthday party). Measures of social communication (e.g. IJA and RJA; use of eye contact; social smiling; and spontaneous giving of items to others) were also tested using several tasks derived from the ADOS-2 (Lord et al., 2012).

Based on previous evidence (e.g. Callaghan & Rankin, 2002; Kirkham et al., 2013; Hartley et al., 2019), we predicted that positive concurrent interrelations would emerge between measures of individual differences (e.g. chronological age, non-verbal intelligence, fine motor skills) and the symbolic domains of pictures, play, and social communication.

More specifically, we expected the pattern of interrelationships to reflect Piagetian domain-general accounts of symbolic development, whereby bidirectional relationships exist across all three domains. The findings of our study will provide the most detailed account of concurrent relationships between symbolic abilities and individual differences to date and could potentially inform early education practices.

Method

Participants

Participants were 41 neurotypical children (23 males, 18 females; *M* age = 42.66 months, *SD* = 7.61, range = 25–55 months) recruited from mainstream nurseries. All children had normal or corrected-to-normal vision. Receptive and expressive language abilities were measured using the Receptive and Expressive Language modules of the Mullen Scales of Early Learning (Mullen, 1995). Our sample had a mean language comprehension age of 45.12 months (*SD* = 9.47; range = 28–62 months) and a mean language production age of 47.32 months (*SD* = 11.89; range = 26–70 months). Fine motor abilities were measured using the Fine Motor module of the Mullen Scales of Early Learning (Mullen, 1995). The children had a mean score of 46.83 months (*SD* = 9.93; range = 24–65 months). Children's non-verbal intellectual abilities were measured using the Leiter-3 (Roid et al., 2013). The mean (age-normed) IQ was 101.18 (*SD* = 6.19; range 87–113) and the mean Leiter-3 raw score was 47.05 (*SD* = 5.93; range = 32–61 months). All procedures performed in this study were in accordance with the ethical standards of institutional and national research committees. Informed consent was obtained from caregivers prior to their children's participation.

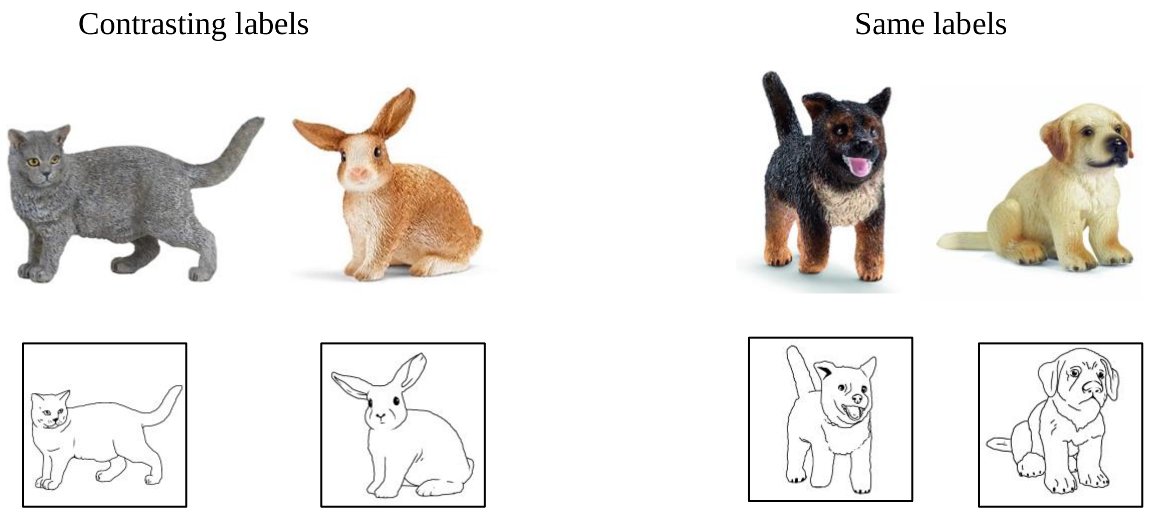
Materials

Picture Comprehension

Stimuli included 16 objects and 16 black-and-white line drawings of those objects. All objects were highly familiar and were selected on the basis that most children understand their linguistic labels by 16 months (Fenson et al., 1994). These objects included: cat, bunny, bicycle, motorbike, hairbrush, comb, plastic carrot, plastic banana, two cars, two dogs, two spoons, and two shells. Perceptual similarity of object pairs was controlled for across trial types. For example, in "contrasting labels" trials (i.e. where choice objects belonged to distinct linguistic categories) a standing cat and a sitting bunny were paired together. In "same labels" trials (i.e. where choice objects belonged to the same linguistic categories) a standing dog and a sitting dog were paired together. All pictures used in this study were laminated and measured 5 cm x 5 cm. Examples of paired object stimuli and black-and-white line drawings are displayed in Figure 1. All line drawings had a broadly similar level of detail to ensure that they did not differ markedly in terms of iconicity.

Figure 1

Examples of object stimuli pairs and line drawings used in the picture comprehension task



Picture Production

Stimuli included six different unfamiliar objects, which were divided into two sets (see Figure 2), pencils, and white A5 paper sheets. The novelty of the items ensured that children's responses could not be facilitated by pre-practised drawing routines associated with familiar concepts.

Figure 2

Objects used in the picture production task

Symbolic Play

In the Free Play task, stimuli included a selection of toys: multiple pop-up toy, nesting cups, two animal figures, board book, toy telephone, four pieces of yarn, gold lid, baby doll with open/shut eyes, eight letter blocks, two identical balls, two identical cars, two pairs of plastic utensils, and four plastic plates. Response to Joint Attention was tested using a remote-controlled bunny. In the Birthday Party task, stimuli included a baby doll with open/shut eyes, a plastic plate, a plastic fork, a plastic knife, a plastic cup, a napkin, a jar of play dough, four glue-gun refill ‘candles’, and a small blanket.

Procedure

Participants were tested individually in their own educational settings, accompanied by a familiar adult when required (e.g. key worker, teacher, or teaching assistant). Children were verbally praised for attention and good behaviour while completing the standardised and experimental assessments, which took the form of fun, short “games” administered in separate sessions, on different days. Order of tasks was randomised for each participant.

Language

The Mullen Scales of Early Learning (MSEL; Mullen, 1995) were used to assess

children’s language comprehension and language production. The Receptive Language module provided a measure of children’s language comprehension. Children completed tasks which involved auditory discrimination and auditory/motor integration e.g. recognition of familiar names and words, identification of objects and pictures, performing simple actions on request, comprehending questions, testing spatial concepts, and identification of colours and numbers. The Expressive Language module provided a measure of children’s language production. Tasks related to overall productive verbal abilities e.g. producing letter sounds, combining words and gestures, naming simple objects, labelling pictures, use of two-word phrases, use of pronouns, counting, use of short sentences, repetition of word sequences, and verbal analogies. Raw scores for both modules were converted into age equivalents based on the normed guidelines in the assessment handbook.

Non-verbal Intelligence

The Leiter International Performance Scale Third Edition (Leiter-3; Roid et al., 2013) was used to test children’s non-verbal intelligence and provide a measure of IQ. The Brief Assessment comprises four sub-tests of visualisation and reasoning that, together, provide a reliable measure of the respondent’s IQ. These sub-tests assess children’s ability to match colours, pictures, and shapes, identify specific features of pictures, mentally rotate images, and to infer/complete patterns. Participants’ raw scores (possible range: 0–152) and IQ scores (possible range 0–170) were calculated as per the guidelines in the assessment handbook.

Fine Motor Skills

The Fine Motor module of the MSEL (Mullen, 1995) was administered to provide a measure of children’s fine motor skills. Children completed tasks which involved motor planning and motor control. Some activities required bilateral manipulation (e.g. unscrewing/screwing a nut and bolt, threading beads, folding, and cutting) and others involved unilateral manipulation (e.g. stacking blocks, inserting pennies in slots, and drawing/writing). Raw scores were converted into age equivalents based on the normed guidelines in the assessment handbook.

Symbolic Play

Tasks derived from the Autism Diagnostic Observation Schedule Version 2 (ADOS-2; Lord et al., 2012) provided a measure of children's symbolic play. The ADOS-2 is a semi-structured, standardised assessment of communication, social interaction, play, and restricted and repetitive behaviours. While this "gold standard" diagnostic tool is predominantly used to aid clinicians and researchers in diagnosing and describing autism spectrum disorder, the current study used elements of the ADOS-2 with neurotypical participants to enable observation and assessment of children's symbolic play skills during spontaneous, independent free play, and the context of a familiar social routine. An adapted scoring system was created to allow for in vivo scoring (see Appendix A).

Free Play. This task provided an opportunity for children to independently interact with a selection of toys arranged on a table in front of them. Initially, the experimenter directed the child's attention to the various toys ("Look at these toys. You can play with them."). Children were allowed to play without interruption for 3 minutes. If the child did not engage in any play during this time or played exclusively with one toy in a limited and/or repetitive manner, the experimenter re-directed the child's attention to the various toys ("What can you do with these toys?"). If necessary, the experimenter also removed the main preoccupation. If the child had not exhibited any spontaneous pretend play after 3 minutes, the experimenter instructed the child to "Look…" and modelled simple pretend play (e.g. feeding the doll using a fork) for them to copy ("You do it."). Children were then allowed to play independently for a further 2–3 minutes.

During the Free Play task, the experimenter recorded which toys the child interacted with and categorised each interaction/play sequence using the following three categories: i) spontaneous pretend play, ii) functional play, iii) limited, repetitive play or no play. If a child demonstrated one or more instances of spontaneous pretend play (e.g. giving a doll a drink from a cup or pretending to talk on a toy telephone), they received two points. Instances of spontaneous pretend play which involved object substitution (i.e. using one object to stand for another) and/or attribution of agency (e.g. involving a figure or doll in an action) were noted. One or more observed instances of object substitution (e.g. pretending yarn is spaghetti) received an additional point. One or more observed instances of attributing agency (e.g. moving a figure or doll as if it is capable of action) scored an additional point. If a child did not demonstrate any instances of spontaneous pretend play, but exhibited functional play (e.g. stacking nesting cups or interacting with cause-and-effect toys), they achieved a total score of 1. Limited, repetitive play (e.g. mouthing or banging objects) or no play attracted a score of zero. Total ‘Free Play’ scores could range from 0–4. The experimenter also noted whether adult intervention/modelling was required (0 = no modelling required; 1 = modelling required), and if so, whether the child imitated the modelled pretend play (0 = imitation; 1 = no imitation). If the child demonstrated an unusual sensory interest in play materials, such as flicking the doll’s eyelids, this was also noted (0 = no observed instances of unusual sensory interest; 1 = one or more observed instances of unusual sensory interest).

Birthday Party. This task assessed children’s functional and symbolic play skills in the context of a familiar social routine. The experimenter observed how children engaged with the doll/other materials, their degree of spontaneity, and evaluated whether the children understood the script of the party scenario. The task involved seven sequential stages:

Putting Candles on Cake. First, the experimenter introduced the doll and explained, “It’s Baby’s birthday, let’s have a birthday party.” Next, the experimenter patted the play dough on a plate (“Here’s the birthday cake…”), placed a ‘candle’ on the cake, handed one candle to the child and left the other two in reach (“Here are the candles.”). If the child put the candles on the cake, they scored one point.

Singing Happy Birthday. The experimenter then 'lit' the candles with a pretend match, shook it out saying "Hot" and asked, "What should we do now?" If the child did not respond, the experimenter said, "Let's sing Happy Birthday!" and started to sing. If the child sang, they scored one point.

Blowing out Candles. If the child did not spontaneously blow out the candles or help the doll to do so, the experimenter prompted "Let's blow out the candles!" If the child helped the baby to blow out the candles using the doll as an independent agent, they achieved a score of three for this item. If the child blew out the candles but did not use the doll as an independent agent, they scored two points. If the child imitated blowing out the candles after explicit demonstration, they scored one point.

Feeding Baby. The experimenter then gave the fork to the child and said, "Baby's hungry." If the child fed the baby immediately, they scored three points. If the child fed the baby after a second prompt ("Baby wants birthday cake…"), they scored two points. If the child fed the baby after explicit demonstration, they scored one point.

Giving Baby a Drink. The experimenter prompted "Baby's thirsty." If the child used the nearby cup to give the baby a drink, they scored one point.

Cleaning Up. The experimenter knocked over the cup, saying "Oh no, I spilled the drink! What should we do?" If the child immediately cleaned up (either using the nearby napkin, using another item as if it were a napkin, or simply pretending to hold a napkin), they scored three points. If the child cleaned up after a second prompt ("Can you help clean up?"), they scored two points. If the child cleaned up after being handed the napkin, they scored one point.

Putting Baby to Bed. The experimenter prompted "Baby is tired." If the child immediately used the blanket (placed within reach on the table) to cover the baby, they achieved a score of three points. If the child used the blanket to cover the baby after the second prompt (“Baby is tired, time for bed…”), they scored two points. If the child covered the baby with the blanket, after being handed it, they scored one point. Total scores for the Birthday Party task ranged from 0–15.

Videos from 10% of participants were independently coded by a second rater who was naïve to the participants’ details and the study’s hypotheses. Interrater reliability was calculated for each of the symbolic play tasks. There was complete agreement (k = 1.00, p = .008) on each individual aspect of the symbolic play tasks (i.e. Free Play and Birthday Party).

Social Communication

Tasks derived from the ADOS-2 (Lord et al., 2012) provided a measure of children’s social communication skills. The current study used elements of the ADOS-2 with neurotypical participants to ‘press’ for communication and social interaction during structured and unstructured situations. The experimenter also noted whether the child demonstrated unusual eye contact (0 = unusual; 1 = not unusual). During both the Free Play and Birthday tasks, the experimenter also noted whether the child spontaneously gave items to the experimenter (0 = no observed instances of giving; 1 = one or more observed instances of giving), or spontaneously initiated joint attention (2 = clear attempt to direct experimenter’s attention towards a distal referent, and child looks back at the experimenter AND the referent; 1 = attempt to direct experimenter’s attention towards a distal referent, but child does not look back at experimenter OR referent; 0 = no attempts to direct experimenter’s attention towards a distal referent). An adapted scoring system was created to allow for in vivo scoring (see Appendix B).

Response to Name. This task probed whether the child responded to their name being called by the experimenter. While the child was engaged with a toy, the experimenter moved behind and to the side of the child and called their name. If the child did not turn and make eye contact, the experimenter gave the child four more opportunities to respond. If the child looked at the experimenter and made eye contact after the first or second press, the child scored three points. If the child made an appropriate vocal response (e.g. “What?”, “Huh?”, “Yes?”) but did not look, the experimenter re-administered this measure later. If the child looked towards the experimenter after the third or fourth press, they scored two points. If the child did not make eye contact, but shifted gaze briefly, or looked towards an interesting vocalisation, they scored one point.

Response to Joint Attention. This task examined whether the child responded to the experimenter’s gaze shift/head movement to locate a target object that was concealed and out of reach. The experimenter initiated this activity when the child was already engrossed with another toy. Importantly, the experimenter never verbally referred to the toy at any point during this task.

First, the experimenter established the child’s attention by calling, “[child’s name], look!”, then overtly shifted their gaze towards the referent (bunny), then back to the child. If the child followed the experimenter’s gaze, the experimenter activated the toy and the child scored three points. If the child did not follow the experimenter’s gaze, the experimenter called, “[child’s name], look at THAT!”, then overtly shifted their gaze towards the referent, then back to the child up to two times. If the child followed the experimenter’s gaze on either press, the experimenter activated the toy and the child scored two points. If the child did not follow the experimenter’s gaze, the experimenter called, “[child’s name], look at THAT!”, then pointed at the referent, overtly shifted their gaze towards the bunny, then back to the child up to two times. If the child followed the experimenter’s point on either press, the experimenter activated the toy and the child scored one point.

Responsive Social Smile. The objective of this task was to identify whether the child smiled in response to a purely social overture (laughter did not count). The experimenter initiated this activity when the child was not already smiling.

First, the experimenter established the child's attention by calling their name, and then said, "Look at you!" while smiling. If the child immediately smiled in response to the first or second smile, they scored three points. If the child partially smiled after the first or second smile, they scored two points. If the child did not respond, the experimenter allowed the child to continue with their activity for a moment, and then repeated the initial prompt. If the child smiled back after this additional press, they scored two points. If not, the experimenter touched the child to evoke a smile. If the child smiled in response to physical contact, they scored one point.

Videos from 10% of participants were independently coded by a second rater who was naïve to the participants' details and the hypotheses in this study. Interrater reliability was calculated for each of the social-communication tasks. There was complete agreement on Response to Name ($k = 1.00$; $p = .008$), Response to Joint Attention ($k = 1.00$; $p = .008$), Responsive Social Smile ($k = 1.00$; $p < .001$), and Eye Contact ($k = 1.00$; $p = .008$). Interrater reliability was substantial for Giving ($k = 0.70$; $p = .053$) and Spontaneous Initiation of Joint Attention ($k = 0.75$; $p = .013$).

Picture Comprehension

A picture-object matching task (Callaghan, 2000) was used to assess children's picture comprehension. Pictures and referent objects were used as stimuli in this task. Children were presented with a black-and-white line drawing of an object for 4s. The experimenter pointed to the depicted object and instructed the child to "Look at this picture!" The drawing was then removed from view, and two choice objects were presented – a target and a foil – approximately 30cm apart and equidistant from the participant. The experimenter asked children to "find the one in the picture."

There were two trial types: contrasting labels (CL) and same labels (SL). Children completed 16 trials in total (eight of each type). In CL trials, the choice objects were familiar and belonged to distinct linguistic categories (cat, bunny, bicycle, motorbike, hairbrush, comb, plastic carrot, plastic banana). Crucially, children's picture-object matching in CL trials could be scaffolded by verbally labelling the picture and matching to a referent object with the same label. In SL trials, the choice objects were familiar but belonged to the same linguistic categories (two cars, two dogs, two spoons, two shells). Although, the items in SL trials were familiar, children's picture-object matching could not be scaffolded by verbal labelling; both potential referents had the same label, and therefore could only be discriminated based on resemblance to the picture. Perceptual similarity of object pairs was controlled for across trial types. The order of trial types was randomised for each participant, subject to the criterion that no more than two trials of the same type (CL or SL) were presented consecutively.

In accordance with standard coding criteria (e.g. Allen et al., 2015; Hartley & Allen, 2015a; Preissler, 2008), only intentional responses were coded (e.g. giving or sliding an object to the experimenter, pointing to, or picking up and showing the experimenter an item). For example, if a child manually explored the foil object having already clearly indicated that the target was the depicted referent via pointing or vocalisation, their response was coded as correct. If children correctly identified the depicted target object, they scored one for that trial. If they incorrectly identified the foil, they scored zero. Total scores could range from 0–16 and performance on each trial type could range from 0–8.

Picture Production

An object-drawing task based on Kirkham et al. (2013) was used to assess children's picture production. Children were provided with a pencil and paper and instructed to draw six unfamiliar objects that were presented individually. Objects were selected on the basis that they could be drawn using circles and/or lines, as these tend to be the first drawing units that appear in children's early drawing attempts (Levin & Bus, 2003). Therefore, failure to produce an accurate representation of each object in the task should not be attributable to a motor production difficulty (Callaghan & Rankin, 2002).

For three objects, the experimenter modelled drawing a simple picture of the target object before the child created their drawing (Modelled Trials). The experimenter instructed participants to "watch carefully" while they were drawing and then highlighted the symbolic relationship between their drawing and the target object ("This drawing shows this object"). The experimenter's drawing was then removed before the child started drawing ("Now, can you draw this object?"). These trials enabled us to assess children's picture production abilities when receiving explicit adult scaffolding. For the other three objects, the experimenter did not provide a demonstration before children created their drawings (Unmodelled Trials). This manipulation allowed us to gain a more precise account of children's picture production abilities under conditions that varied in difficulty. Participants were randomly assigned one of four different presentation orders that varied in terms of the objects allocated to Modelled and Unmodelled Trials and the order of trial types. No more than two trials of the same type were presented consecutively, and children were given up to five minutes to produce each drawing.

Every drawing was coded by the first experimenter and an independent rater with expertise in the field who was blind to the study's objectives, the participant's details, and whether the trial was Modelled or Unmodelled. The drawings were presented to the independent rater individually, and they were asked to identify which of the six possible objects the child had depicted. If the rater matched the drawing to the correct referent object, children scored one (an incorrect match scored zero). Inter-rater reliability was very high (k = .97, p < .001).

At another time, as part of the overall battery of assessments, children also completed a Free Draw control task, to determine if they were capable of independently drawing representational pictures composed of circles and lines. Children were provided with a pencil and paper (for a maximum of 5 minutes) and instructed to "Draw a picture. You can draw anything you want to." Every drawing was coded by the first experimenter and an independent rater with expertise in the field who was naïve to the participants' details and the hypotheses in this study. Both raters were required to judge whether it was possible to: i) recognise what, if anything, was represented (0 = scribble/accidental markings; 1 = controlled, representational markings), ii) identify circles (0 = no circles; 1 = one or more circles), and iii) identify lines (0 = no lines; 1 = one or more lines). Inter-rater reliability was very high (Representational: $k = .90$, $p < .001$; Circles: $k = 0.97$; $p < .001$; Lines: $k = 1.00$; $p < .001$).

Results

Examining Individual Differences Within Domains

To investigate the influence of individual differences within domains, data generated by the battery of standardised assessments and experimental tasks were analysed via generalised linear mixed effects models and linear mixed effects models using the glmer and lmer functions from the lme4 package in R (Bates et al. 2015), or multiple regression models. Receptive Language, Expressive Language and Fine Motor Skills were coded as the participant's age equivalent score on the corresponding modules of the Mullen Scales of Early Learning. Non-verbal Intelligence was coded as the participant's raw score on the Leiter-3. Chronological Age was coded as the participant's age in months. For each analysis, we started with a baseline model containing only by-participant and by-item random intercepts to account for variation across participants and stimuli. Fixed effects were added individually, and we tested whether their inclusion significantly improved predictive fit. Please refer to Appendix C for full details of the model building processes for all analyses.

Picture Comprehension

Trial Number was coded 1–16, based on the order of trial administration, and was tested as a fixed effect to rule out practice effects. Accuracy was coded as 0 (incorrect) and 1 (correct). The mean score in the Contrasting Labels Condition was 0.97 (*SD* = 0.62) and the mean score in the Same Labels Condition was 0.92 (*SD* = 0.89). The likelihood of responding correctly by chance was 50%. Trial Type was contrast coded as -0.5 (Contrasting Labels Condition) and +0.5 (Same Labels Condition). The analysis included 656 trials in total.

A model containing only Non-verbal Intelligence as a fixed effect provided the best fit to the observed data (see Table 1), suggesting that increased likelihood of correctly identifying the depicted target object was associated with higher Leiter-3 raw scores.

Table 1

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of children's picture comprehension accuracy, predicted by Non-verbal Intelligence

Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	-1.44	2.20	-0.66	.512
Non-verbal Intelligence	0.12	0.05	2.43	.015*
	AIC	BIC	logLik	deviance
	248.2	266.1	-120.1	240.2

Picture Production

Trial Number was coded 1–6, based on the order of trial administration, and was included as a fixed effect to rule out practice effects. Accuracy was coded as 0 (incorrect) and 1 (correct). The mean score in the Unmodelled Trials Condition was 0.60 (*SD* = 1.19) and the mean score in the Modelled Trials Condition was 0.67 (*SD* = 1.12). Trial Type was contrast coded as -0.5 (Unmodelled Trials Condition) and +0.5 (Modelled Trials Condition). The analysis included 246 trials in total.

A model containing Trial Type, Chronological Age and Fine Motor Skills provided the best fit to our observed data (see Table 2). These results suggest that increased likelihood of generating representational drawings that could be matched to their intended referents was associated with responding in modelled trials (rather than unmodelled trials), older age, and more developed fine motor skills.

Table 2

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of children's picture production accuracy, predicted by Trial Type, Chronological Age, and Fine Motor Skills

Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	-15.41	2.68	-5.76	< .001*
Trial Type	1.03	0.45	2.30	.022*
Chronological Age	0.14	0.06	2.41	.016*
Fine Motor Skills	0.23	0.05	4.62	< .001*
	AIC	BIC	logLik	deviance
	191.5	212.5	-89.7	179.5

Free Play

Based on the participant's raw scores on the adapted ADOS Free Play task, Total Toys was coded 0–13 (*M* = 6.73, *SD* = 1.88), Highest Level of Play was coded 0–2 (*M* = 1.76, *SD* = 0.43), and all of the following measures were coded 0–1: Uses Toys as Agents (*M* = 0.63, *SD* = 0.49), Object Substitution (*M* = 0.63, *SD* = 0.49), Unusual Sensory Interest (*M* = 0.02, *SD* = 0.16), Adult Intervention Required (*M* = 0.39, *SD* = 0.49) and Imitates Modelled Play (*M* = 0.22, *SD* = 0.42).

As participants contributed only one data point each, relationships between measures of play and participant individual differences were explored via multiple regression modelling rather than mixed-effects modelling, with comparisons drawn between models of varying complexity to identify the most parsimonious and best-fitting explanation for each dependent variable. Each analysis started by entering all participant demographic features simultaneously (Chronological Age, Receptive Language, Expressive Language, Fine Motor Skills, and Non-verbal Intelligence). The second model contained only the predictors identified as significant in Model 1. A model comparison was conducted to confirm that there was no significant decrease in fit between Model 1 and Model 2. Then, in Model 3, all the non-dependent play measures were entered simultaneously alongside the significant demographic predictors. Where no significant predictors were identified in Model 1, the non-dependent play measures were entered in Model 2 instead. In Model 4, all the non-significant play measures were removed, and a model comparison was conducted between Model 3 and Model 4 to confirm that there was no significant decrease in fit. Thus, for most analyses, Model 4 represents the most parsimonious and best-fitting explanation for each dependent variable (or Model 3 if no significant predictors were identified in Model 1).

Total Toys

Total Toys was best predicted by Non-verbal Intelligence (β = 0.11 p = .008) and Object Substitution (β = 2.27, p <.001), $F(2, 38) = 20.90$, $p < .001$, adjusted $R^2 = 0.50$. These results suggest that playing with a higher number of toys was associated with higher Leiter-3 raw scores and an increased likelihood of object substitution.

Highest Level of Play

Highest Level of Play was best predicted by Toys as Agents (β = 0.45 p < .001) and Object Substitution (β = 0.45 p < .001), $F(2, 38) = 59.67$, $p < .001$, adjusted $R^2 = 0.75$. These results suggest that engaging in more sophisticated play was associated with an increased likelihood of playing with a higher number of toys and using toys as agents.

Uses Toys as Agents

Uses Toys as Agents was best predicted by Highest Level of Play (β = 0.71, p < .001), Object Substitution (β = -0.31, p = .034) and Adult Intervention Required (β = -0.49, p = .001), $F(3, 37) = 27.39$, p < .001, adjusted R^2 = 0.66. These results suggest that using toys as agents was associated with an increased likelihood of engaging in more sophisticated play, decreased likelihood of object substitution, and a reduction in the need for adult intervention.

Object Substitution

Object Substitution was best predicted by Total Toys (β = 0.10, p = .004) and Highest Level of Play (β = 0.83, p < .001), $F(3, 37) = 23.99$, p < .001, adjusted R^2 = 0.63. Uses Toys as Agents (β = -0.28, p = .067) was not significant. These results suggest that substituting toys to stand for something else was associated with an increased likelihood of interacting with a higher number of toys, engaging in more sophisticated play, and decreased likelihood of using toys as agents.

Unusual Sensory Interest

Unusual Sensory Interest was not predicted by any of the play measures or individual differences across participants.

Adult Intervention Required

Adult Intervention Required was best predicted by Uses Toys as Agents (β = -0.48, p < .001), Imitates Modelled Play (β = 0.49, p < .001) and Object Substitution (β = -0.28, p = .002), $F(3, 37) = 50.05$, p < .001, adjusted R^2 = 0.79. These results suggest that requiring adult intervention during play was associated with a reduced likelihood of spontaneously using toys as agents, a reduced likelihood of spontaneously using an object to represent something else, and an increased likelihood of imitating modelled play.

Imitates Modelled Play

Imitates Modelled Play was not predicted by any of the play measures or individual differences across participants.

Birthday Party

Based on the maximum number of points available for the separate trials, pass/fail variables were coded 0–1: Putting Candles on Cake, Singing Happy Birthday, and Giving Baby a Drink, and experimenter-scaffolded variables were coded 0–3: Blowing out Candles, Feeding Baby, Cleaning Up, and Putting Baby to Bed. Relationships between these measures of play and participant individual differences were explored via generalised linear mixed-effects modelling for 0–1 trials, and linear mixed-effects modelling for 0–3 trials. The maximum total score for the Birthday Party task was 15 (*M* = 12.39, *SD* = 2.19). The analysis included 287 trials in total.

0–1 Trials (Putting Candles on Cake, Singing Happy Birthday, Giving Baby a Drink)

A model containing Chronological Age and Expressive Language as fixed effects provided the best fit to the observed data (see Table 3). These results suggest that children who were younger and had more developed expressive language skills were more likely to score a 1 on 0–1 Birthday Party trials.

Table 3

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of children's performance on 0–1 trials, predicted by Chronological Age and Expressive Language

Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	14.21	9.04	1.57	.116
Chronological Age	-0.19	0.07	-2.61	.009
Expressive Language	0.10	0.05	2.13	.033
	AIC	BIC	logLik	deviance
	65.6	79.7	-27.8	55.6

0–3 Trials (Blowing out Candles, Feeding Baby, Cleaning Up, and Putting Baby to Bed)

A model containing Receptive Language as a fixed effect provided the best fit to our observed data (see Table 4). These results suggest that increased likelihood of attaining higher scores in 0–3 Birthday Party trials was associated with more developed Receptive Language skills.

Table 4

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of children's performance on 0–3 trials, predicted by Receptive Language

Fixed effects	Estimated coefficient	Std. error	*t*	Pr(>|z|)
(Intercept)	1.66	0.35	4.71	< .001
Receptive Language	0.02	0.01	2.37	.023
	AIC	BIC	logLik	deviance
	345.6	361.1	-167.8	335.6

Social Communication

Based on the participant's raw score on the corresponding modules of the adapted ADOS social-communication tasks, Response to Name (M = 2.90, SD = 0.44), Response to Joint Attention (M = 2.73, SD = 0.50), and Social Smile (M = 2.66, SD = 0.76) were coded 0–3, and Eye Contact (M = 0.90, SD = 0.30), Giving (M = 0.27, SD = 0.45), and Initiation of Joint Attention (M = 0.22, SD = 0.52) were coded 0–1.

As participants contributed only one data point each, relationships between measures of social communication and participant individual differences were explored via multiple regression modelling rather than mixed-effects modelling, with comparisons drawn between models of varying complexity to identify the most parsimonious and best-fitting explanation for each dependent variable.

We entered all of the social communication measures together in the first block, and then subsequently added each of the demographic variables in the second block. By taking this approach, which is comparable to the regression analyses conducted by Kirkham et al. (2013), we were able to discretely investigate the relationships between Response to Name, Response to Joint Attention, Social Smile, Eye Contact, Giving and Initiation of Joint Attention, and then subsequently investigate how these relationships are impacted by Chronological Age, Receptive Language, Expressive Language, Fine Motor Skills, and Non-verbal Intelligence.

Response to Name

Response to Name was best predicted by Response to Joint Attention ($\beta = 0.26$, $p = .022$) and Eye Contact ($\beta = 0.79$, $p < .001$), $F(2, 38) = 22.56$, $p < .001$, adjusted $R^2 = 0.52$. These results suggest that likelihood of responsive social smiling was associated with higher Response to Joint Attention scores and appropriate eye contact with the examiner.

Response to Joint Attention

Response to Joint Attention was best predicted by Response to Name ($\beta = 0.65$, $p < .001$), $F(1, 39) = 18.14$, $p < .001$, adjusted $R^2 = 0.30$. These results suggest that increased likelihood of following the examiner's gaze toward a specific referent was associated with higher Response to Name scores.

Social Smile

Social Smile was best predicted by Eye Contact ($\beta = 1.28$, $p < .001$), $F(1, 39) = 13.43$, $p < .001$, adjusted $R^2 = 0.26$. These results suggest that increased likelihood of responsive social smiling was associated with increased appropriate eye contact with the examiner.

Eye Contact

Eye Contact was best predicted by Response to Name ($\beta = 0.40$ $p < .001$) and Social Smile ($\beta = 0.12$ $p = .013$), $F(2, 38) = 23.69$, $p < .001$, adjusted $R^2 = 0.53$. These results suggest that increased likelihood of making appropriate eye contact with the examiner was associated with higher Response to Name scores and increased responsive social smiling.

Giving

Giving was not predicted by any of the social skills or individual differences across participants.

Initiation of Joint Attention

Initiation of Joint Attention was best predicted by Fine Motor Skills ($\beta = 0.17$ $p = .039$), $F(1, 39) = 4.55$, $p = .039$, adjusted $R^2 = 0.08$. These results suggest that increased likelihood of spontaneously attempting to direct the examiner’s attention to a distal referent was associated with more developed fine motor skills.

Examining Interrelations Between Play, Pictures, and Social Communication

To examine interrelations between symbolic domains, data generated by the battery of standardised assessments and experimental tasks were analysed via generalised linear mixed effects models and linear mixed effects models using the glmer and lmer functions from the lme4 package in R (Bates et al., 2015), or via multiple regression models. All models contained by-participant and by-item random intercepts to account for variation across participants and stimuli. Non-verbal Intelligence was coded as the participant's raw score on the Leiter-3. Free Play and Birthday Party were coded as the participant's raw scores on the adapted ADOS symbolic play tasks. Picture Comprehension was coded as the participant's raw score on the Picture Comprehension task, and both trial types (Same Labels and Contrasting Labels) were coded as 0–3. Picture Production was coded as the participant's raw score on the Picture Production task, and both trial types (Modelled and Unmodelled) were coded as 0–3. Social Communication was coded as the participant's raw score on the adapted ADOS social-communication task, and each individual trial was coded as either 0–3 (Response to Name, Response to Joint Attention, Social Smile) or 0–1 (Eye Contact, Giving and Initiation of Joint Attention). Independent Drawing was coded as participant's raw score on the Free Draw Task. For each analysis, we started with a baseline model containing the variables that were identified as significant in the preceding analyses for each task. Fixed effects were added individually, and we tested whether their inclusion significantly improved predictive fit. Please refer to Appendix C for full details of the model building processes for all analyses.

Picture Comprehension

This analysis included 656 trials in total. The baseline model, containing only Non-verbal Intelligence as a fixed effect, provides the best fit to our observed data (see Table 1).

Picture Production

This analysis included 246 trials in total. A model containing Trial Type, Chronological Age, Fine Motor Skills, and Free Play as fixed effects, provided the best fit to our observed data (see Table 5). In addition to the effects of Trial Type, Chronological Age, and Fine Motor Skills, these results suggest that increased likelihood of generating representational drawings that could be matched to their intended referents was associated with more developed play skills.

Table 5

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of children's picture production accuracy, predicted by Trial Type, Chronological Age, Fine Motor Skills, and Free Play score

Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	-15.70	2.60	-6.04	< .001*
Trial Type	1.02	0.45	2.29	.023*
Chronological Age	0.13	0.05	2.45	.014*
Fine Motor Skills	0.21	0.05	4.34	< .001*
Free Play	0.53	0.25	2.11	.035*
	AIC	BIC	logLik	deviance
	189.2	213.8	-87.6	175.2

Free Play

Based on the participant's raw scores on the adapted ADOS Free Play task, Total Toys was coded 0–13, Highest Level of Play was coded 0–2, and all of the following measures were coded 0–1: Uses Toys as Agents, Object Substitution, Unusual Sensory Interest, Adult Intervention Required and Imitates Modelled Play. The analysis included 41 trials in total. Interrelations between measures of play, pictures and social communication were explored via multiple regression modelling, with comparisons drawn between models of varying complexity to identify the most parsimonious and best-fitting explanation for each dependent variable.

Total Toys

A model containing Non-verbal Intelligence, Object Substitution and Independent Drawing was taken as the final best-fitting model for Total Toys, $F(3, 37) = 15.97$, $p < .001$, adjusted $R^2 = 0.53$ (see Table 6). Non-verbal Intelligence ($\beta = 0.09$ $p = .035$) and Object Substitution ($\beta = 2.21$, $p < .001$) were significant predictors. Independent Drawing ($\beta = 0.30$ $p = .072$) approached significance. In addition to the effects of Non-verbal Intelligence and Object Substitution, these results suggest that children with more developed independent drawing skills were more likely to interact with a higher number of toys compared to children with less developed independent drawing skills.

Table 6

Summary of the fixed effects in the final multiple regression model of children's total interaction with toys, predicted by Non-verbal Intelligence, Object Substitution, and Independent Drawing

Fixed effects	Estimated coefficient	Std. error	t	Pr(>|z|)
(Intercept)	0.07	1.75	0.04	.967
Non-verbal Intelligence	0.09	0.04	2.18	.035
Object Substitution	2.21	0.43	5.14	< .001
Independent Drawing	0.30	0.16	1.85	.072

Highest Level of Play

Highest Level of Play was best predicted by Uses Toys as Agents ($\beta = 0.43$ $p < .001$), Object Substitution ($\beta = 0.41$, $p < .001$) and Social Smile ($\beta = 0.09$, $p = .071$) which approached significance, $F(3, 37) = 43.51$, $p < .001$, adjusted $R^2 = 0.76$. In addition to the effects of Uses Toys as Agents and Object Substitution, these results suggest that children who were more likely to smile socially in response to the experimenter exhibited more sophisticated symbolic play skills during independent free play.

Uses Toys as Agents

Uses Toys as Agents was best predicted by Highest Level of Play (β = 0.62 p = .001), Object Substitution (β = -0.35, p = .011), Adult Intervention Required (β = -0.50, p < .001) and Picture Production (β = 0.06, p = .007), $F(4, 36) = 26.62$, $p < .001$, adjusted $R^2 = 0.72$. In addition to the effects of Highest Level of Play, Object Substitution and Adult Intervention Required, these results suggest that children who used toys as agents during independent free play were more likely to achieve higher Picture Production scores compared to children who did not attribute agency to toys.

Object Substitution

None of the models significantly differed in fit when compared with the baseline model. These results demonstrate a lack of interrelations between Object Substitution and the other social-communicative and symbolic domains.

Unusual Sensory Interest

Unusual Sensory Interest was best predicted by Social Smile (β = -0.07 p = .026), $F(1, 39) = 5.39$, $p = .026$, adjusted $R^2 = 0.10$, suggesting that children who demonstrated unusual sensory interests during independent free play were less likely to smile socially in response to the experimenter than children who did not demonstrate unusual sensory interests.

Adult Intervention Required

Adult Intervention Required was best predicted by Uses Toys as Agents (β = -0.46 p < .001), Imitates Modelled Play (β = 0.43, p < .001), Object Substitution (β = -0.23 p = .009) and Social Smile (β = -0.12 p = .023), $F(4, 36) = 43.65$, $p < .001$, adjusted $R^2 = 0.81$. In addition to the effects of Uses Toys as Agents, Imitates Modelled Play, and Object Substitution, these results suggest that children who required adult intervention during independent free play were less likely to smile socially in response to the experimenter compared to children who did not require adult intervention.

Imitates Modelled Play

Imitates Modelled Play was best predicted by Adult Intervention Required ($\beta = 0.62$, $p < .001$) and Unmodelled Trials ($\beta = 0.10$ $p = .027$), $F(2, 38) = 19.65$, $p < .001$, adjusted $R^2 = 0.48$. In addition to the effect of Adult Intervention Required, these results suggest that children who imitated play actions modelled by the experimenter were more likely to achieve higher accuracy on Unmodelled Trials in the Picture Production task.

Birthday Party

This analysis included 287 trials in total.

0–1 Trials (Putting Candles on Cake, Singing Happy Birthday, Giving Baby a Drink)

A model containing Chronological Age, Expressive Language and Free Play as fixed effects provided the best fit to our observed data (see Table 7). Increased likelihood of attaining a score of 1 in the 0–1 Birthday Party trials was associated with younger chronological age, more developed expressive language skills, and more developed play skills.

Table 7

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of children's performance on 0–1 trials, predicted by Chronological Age, Expressive Language and Free Play

Fixed effects	Estimated coefficient	Std. error	*t*	Pr(>|z|)
(Intercept)	15.67	10.78	1.45	.146
Chronological Age	-0.27	0.09	-2.86	.004
Expressive Language	0.14	0.06	2.34	.019
Free Play	0.48	0.23	2.15	.032
	AIC	BIC	logLik	deviance
	62.6	79.4	-25.3	50.6

0–3 Trials (Blowing out Candles, Feeding Baby, Cleaning Up, and Putting Baby to Bed)

A model containing Receptive Language and Contrasting Labels Trials as fixed effects provided the best fit to our observed data (see Table 8). Increased likelihood of attaining higher scores in the 0–3 Birthday Party trials was associated with more developed Receptive Language skills and lower scores on Contrasting Labels trials.

Table 8

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of children's performance on 0–3 trials, predicted by Receptive Language and Contrasting Labels Trials

Fixed effects	Estimated coefficient	Std. error	*t*	Pr(>|z|)
(Intercept)	2.92	0.62	4.68	< .001
Receptive Language	0.02	0.01	2.70	.010
Contrasting Labels Trials	-0.18	0.07	-2.38	.022
	AIC	BIC	logLik	deviance
	342.3	360.9	-165.1	330.3

Social Communication

Interrelations between measures of social communication, play and pictures were explored via multiple regression modelling, with comparisons drawn between models of varying complexity to identify the most parsimonious and best-fitting explanation for each dependent variable.

Response to Name

Response to Name was best predicted by Response to Joint Attention (β = 0.23 p = .032), Eye Contact (β = 0.75, p < .001), and Modelled Trials (β = 0.11 p = .008), F(3, 37) = 20.28, p < .001, adjusted R^2 = 0.59. These results suggest that increased likelihood of children responding to their name with eye contact was associated with higher Response to Joint Attention scores, increased appropriate eye contact with the examiner, and higher scores on modelled picture production trials.

Response to Joint Attention

None of the models significantly differed in fit when compared with the baseline. These results demonstrate a lack of interrelations between Response to Joint Attention and the other social-communicative and symbolic domains.

Social Smile

Social Smile was best predicted by Eye Contact (β = 1.23 p = .001) and Birthday Party (β = 0.12, p = .013), F(2, 38) = 11.15, p < .001, adjusted R^2 = 0.34. These results suggest that increased likelihood of children socially smiling was associated with increased appropriate eye contact with the examiner and higher scores on the Birthday Party task.

Eye Contact

None of the models significantly differed in fit when compared with the baseline model. These results demonstrate a lack of interrelations between Eye Contact and the other social-communicative and symbolic domains.

Giving

Giving was best predicted by Free Play (β = 0.14 p = .011), $F(1, 39) = 7.17$, p = .011, adjusted R^2 = 0.13, suggesting that increased likelihood of independently giving items to the examiner was associated with higher Free Play Scores.

Initiation of Joint Attention

None of the models significantly differed in fit when compared with the baseline model. These results demonstrate a lack of interrelations between Initiation of Joint Attention and the other social-communicative and symbolic domains.

Discussion

This study examined how various individual differences, including non-verbal intelligence and language proficiency, predicted the abilities of neurotypical 2–5-year-olds' across pictorial, play, and social communication domains, and also modelled concurrent interrelations between these symbolic domains. When we investigated the influence of individual differences within domains, we found that non-verbal intelligence predicted children's picture comprehension accuracy and number of toys interacted with during free play. We also identified that chronological age, fine motor skills, and trial type predicted children's picture production accuracy. Furthermore, chronological age and language predicted children's performance in symbolic play tasks. When we examined interrelations between the non-linguistic symbolic domains, we found that superior picture production skills were associated with more sophisticated symbolic play and social scaffolding, and symbolic play skills were predicted by variability in pictorial understanding and social communication skills. Moreover, we identified that social communication skills were predicted by picture production and symbolic play.

Children's picture comprehension accuracy was associated with greater non-verbal intelligence scores, but not measures of language. As our picture-object matching task specifically manipulated the availability of linguistic scaffolding, an absence of trial type suggests that our participants understood the importance of *resemblance* and were focusing on iconicity (rather than relying on language) to correctly identify the depicted target objects in both conditions. That is, children were able to solve both trial types based on identifying perceptual correspondences between pictures and referents. This ability to detect visual similarities between pictures and objects might be a predominantly non-verbal perceptual skill and could relate to a specific component of intelligence (visual-object intelligence; Blazhenkova & Kozhevnikov, 2010). Although Hartley et al. (2019) demonstrated that both receptive and expressive language skills relate to children's picture comprehension, their participants performed less accurately during same labels trials relative to contrasting labels trials, indicating their use of language to scaffold their choices. Despite being younger, our participants performed more accurately in the picture comprehension task compared to those in previous studies identifying predictive relationships between language and pictures (Hartley et al., 2019; Kirkham et al., 2013).

While participants demonstrated ceiling-level accuracy in the picture comprehension task, this was not the case for picture production. This discrepancy in children's within-domain abilities aligns with previous findings demonstrating superiority of infants' receptive skills relative to their productive skills across communicative domains (Adamson, 1995; Callaghan, 1999; McCune, 1995). Children's picture production accuracy was significantly more accurate in modelled trials, and greater accuracy was predicted by older age, and more developed fine motor skills. These findings are in alignment with Hartley et al. (2019), who found that picture production positively correlated with chronological age but was unrelated to language. As their experiment did not include a measure of fine motor skills, it is possible that chronological age was a proxy for fine motor skills (i.e. older children may have had more developed fine motor skills). However, as both predictors were significant in our study, it appears that age captures additional variance over and above fine motor skills. For example, the effect of age could reflect increased practice/experience producing drawings. Older children may have had more opportunities to create graphic representations, and possibly spent more time watching others draw and assimilating effective strategies compared to younger children.

Although Kirkham et al. (2013) identified positive statistical relationships between graphic symbolism skills and language, they did not investigate trial type or measure children's fine motor skills. It is therefore possible that language did not contribute in our particular tasks because greater proportions of variability in final models were captured by fine motor skills and trial type – variables potentially more relevant to graphic representation. Producing recognisable, representational drawings requires a certain level of physical competence to effectively use and control drawing implements, thus accounting for the influence of fine motor skills. In modelled trials, it is likely that the explicit demonstrations provided by a more competent drawing partner provided an exemplar model that directly scaffolded children's performance, which is consistent with the idea that children's receptive and expressive capabilities in non-linguistic symbolic domains are mediated by social interactions with symbolically competent adults (Callaghan et al., 2011, 2012).

In the Birthday Party task, better performance on trials that involved singing "Happy Birthday", putting candles on a cake, and giving a baby doll a drink, were predicted by younger age and more developed expressive language skills. On the surface, these effects appear contradictory, but it is possible that older children were less inclined to join in with these tasks due to feeling more shy or self-consciousness when singing (Coplan & Evans, 2009). These three tasks required participants to make inferences and perform specific actions without explicitly being told what to do, unlike the other Birthday Party tasks (0–3 trials) where no additional verbal or physical prompts were available to scaffold performance.

Thus, it is possible that older children who have more school-based learning experience were reluctant to “interrupt” the adult and were politely waiting for clear task instructions before acting, akin to the student-teacher dynamic in a classroom (Rimm-Kaufman & Kagan, 2005). However, this theoretical explanation is speculative and warrants further investigation.

Although it is possible that the effect of expressive language was driven by the singing task, our findings are in alignment with previous research evidencing concurrent links between children’s language and play abilities (Christie & Roskos, 2009; Doswell et al., 1994; Lewis et al., 2000; Quinn et al., 2018). Children’s responding on trials that involved blowing out candles, feeding a baby doll, cleaning up a spillage and putting a baby doll to sleep were predicted by more developed receptive language skills. Although this association with receptive language could be attributed to the more detailed narratives within these tasks and requirement for understanding verbal instructions, our findings are broadly consistent with previous research indicating that children’s language and play abilities are related, and provide tentative support for the notion that development in these domains is accelerated by the language of more competent play partners during pretend play episodes (Lillard et al., 2010). In contrast, language did not appear to directly support children’s skills during Free Play. However, this task involved spontaneous, independent play, and there was no direct requirement for them to talk (unlike the Birthday Party task).

Children’s responding on social communication trials was not related to their language abilities. Although there is a wealth of evidence demonstrating that rapidly developing non-linguistic skills scaffold infants’ early vocabulary development (Bruner, 1983; Tomasello & Farrar, 1986), it is possible that the relationship between these variables changes or diminishes later in development. Miranda and colleagues (2020) investigated relationships between the Social Communication Questionnaire (SCQ; Rutter et al., 2003) and pragmatic language and socialisation skills in 7–11-year-olds. They found that reciprocal social interaction predicted daily life social skills but was not associated with pragmatic language. Therefore, the lack of a relationship between social communication and language in our study could be due to the older age and more developed verbal competence of our participants. Children's responding on the Initiation of Joint Attention task was related to fine motor skills; this effect may have been driven by the requirement for children to point with their index finger to direct the examiner's attention to a distal referent (Gonzalez et al., 2019).

In our study, more developed symbolic play skills predicted greater picture production accuracy, and more sophisticated independent free play predicted superior performance when drawing independently. There was also an association between children's accuracy on the Birthday Party task and picture comprehension accuracy. These findings align with prior research reporting relationships between symbolic play and graphic symbolism (Kirkham et al., 2013). The bidirectional relationship evidenced in our data might exist because sophisticated symbolic play and representational drawing are both underpinned by representational insight i.e., the basic realisation of the symbolic relationship between a symbol and its referent (DeLoache, 1995). As children's play skills become more sophisticated, they are increasingly able to attribute agency to inanimate objects and act as if items are something else entirely (Smith & Lillard, 2012; Singer & Singer, 1990). There could also be parallels with children's ability to produce drawings. In understanding a representational drawing, children must have the knowledge that the 2-D graphic markings on a page are representative of something 3-D that is independent of the picture (DeLoache, 1995; Sigel, 1978). This potential mutual dependency on the capacity for symbolic understanding indicates that both these non-linguistic symbolic domains are underpinned by similar cognitive mechanisms (Pleyer, 2020).

Existing theories propose that social communication supports language, and might also support non-linguistic symbolic domains, serving as building blocks that enable children to learn skills through social interaction (Kirkham et al., 2013; Vygotsky, 1962, 1978). However, our data suggest that non-linguistic symbolic skills also predict children's basic foundational social communication skills. It might be that children who are more skilled in symbolic play are more sensitive to others and more likely to engage symbolically in interpersonal play situations, providing further opportunities for developing and refining social communication skills such as joint attention. This interpretation could also be extended to picture production, as drawing is an act of influencing the minds of other people which requires other-mindedness (Rochat & Callaghan, 2005). However, we recommend that future research replicates these findings and investigates these hypotheses.

Our findings provide the most comprehensive account of concurrent relationships between symbolic abilities and individual differences in neurotypical development to date. This has important implications for pedagogy and could inform the content and delivery of educational interventions, suggesting that certain tasks or developmental activities might have cross-domain benefits, as opposed to simply benefitting a single targeted domain. For example, it is possible that children who demonstrate difficulties or delays in one symbolic domain (e.g. drawing pictures) may benefit from play-based interventions that specifically target their use and understanding of skills in other related symbolic domains (i.e. play and social communication). Inter-domain relationships identified by this study could also be exploited by clinical and educational interventions aimed to facilitate symbolic development in children demonstrating delays or differences in development. For example, evidence from randomised controlled trials highlight the potential value and effectiveness of developmental or relationship-based interventions delivered by therapists and teachers (Dawson et al., 2010; Landa et al., 2011). A specific parent-mediated intervention focusing on joint attention and symbolic play facilitated children's initiation of and response to joint attention, symbolic play skills, and predicted more developed expressive language skills one year post-intervention

(Kasari et al., 2006, 2008).

However, it is important to acknowledge the limitations of our study. Although our data indicate how variables interrelate with each other at the time of testing, we are unable to draw any causal, developmental conclusions. It is also difficult to comment on the specific ages at which these relationships change, because we did not examine discrete age groups. Therefore, we recommend that future studies employ longitudinal designs to establish causal relationships between infants' early acquisition and subsequent development of symbol systems, and identify developmental interrelationships between domains (e.g. Kirkham et al., 2013). Furthermore, we recognise there are relationships between some of the measures of individual differences included in our models. For example, chronological age was included as its own factor and was strongly related to receptive and expressive language, and fine motor skills. However, in some of our analyses, chronological age predicted significant additional variability, indicating its unique contribution as a variable of interest.

In summary, the present study revealed concurrent bidirectional interrelationships between pictorial, play, and social communication domains. These findings suggest that non-linguistic symbolic domains are interconnected and potentially underpinned by shared factors, as in previous research (Callaghan & Rankin, 2002; Kirkham et al., 2013). Overall, our findings closely align with domain-general accounts of symbolic functioning whereby social communication, play, and pictorial domains develop in relative synchrony due to generalised cognitive processes (Piaget, 1952). Evidence of reciprocity between pictures and play indicates mutual dependency on representational insight (DeLoache, 2000; Pleyer, 2020). This shared internal mechanism is required to understand that 2-D graphic markings can represent an independent 3-D referent (DeLoache, 1995; Sigel, 1978), and to act 'as if' during episodes of pretend play, attributing agency to toys and exhibiting object substitutions (Lewis et al., 1992). Thus, the attainment of representational insight may lay the foundations for enabling expression of meaning across all symbolic systems, in conjunction with other essential capacities, such as vocal/motor control and visual memory (McCune, 2008).

Chapter 3: How does variability in language, and other individual differences, predict symbolic and social-cognitive abilities in autistic children?

Chapter Introduction

Social communication and language abilities are closely related in early neurotypical development, and may scaffold subsequent development of play and pictorial domains (Kirkham et al., 2013; Vygotksy, 1978). By the preschool years, relationships between social communication, pictures, and play appear to be bidirectional, implicating domain-general communicative mechanisms (Carter & Hartley, in prep a, see Chapter 2). However, autism is characterised by social communication difficulties that could have significant repercussions for non-linguistic symbolic domains. Difficulties with social skills could contribute to differences in autistic children's understanding of pictures and play, and relationships between these domains. However, to date, little research has investigated the complex interactions that may occur across multiple domains simultaneously. This chapter presents a study that aims to bridge this gap by examining concurrent inter-domain relationships between social communication, play, and pictures, alongside other individual differences such as language abilities, non-verbal intelligence, and fine motor skills, in autistic children aged 4 to 11 years.

Author Contribution: *Cheriece Carter*: design, data collection, analysis, writing, review. *Calum Hartley*: design, analysis, review.

Abstract

Despite consistent evidence of delays and differences across multiple symbolic domains in autism spectrum disorder, including language, symbolic play, and pictures, the current research literature lacks a comprehensive examination of concurrent interrelationships across these domains. Understanding the complex interplay between symbolic abilities and individual differences in autistic children is crucial for developing effective educational and clinical interventions. Therefore, the current study investigated how variability in language, and other individual differences, predicted the abilities of 4–11-year-old autistic children in the domains of social communication, play, and pictures, and modelled relationships between these domains. Participants completed a battery of standardised assessments and experimental tasks. Our findings revealed that pictorial understanding and symbolic play were bidirectionally related, and both predicted by social communication and/or social scaffolding. However, proficiency in play and pictorial domains did not seem to reciprocally enhance social communication abilities, as observed in recent evidence from neurotypical children. This suggests that social communication skills potentially scaffold understanding of other non-linguistic symbolic domains. By extension, those children who experience the most severe social challenges are likely to demonstrate more significant challenges with symbolic understanding across play and pictorial domains. Interventions targeting social communication skills may have cascading benefits for understanding in pictures and play.

Introduction

Becoming symbol-minded is a fundamental developmental milestone that involves learning to use and understand a multitude of symbol systems, including gestures, pictures, and words (DeLoache, 2004). These systems are cultural conventions that must be acquired from others and, once mastered, enable children to communicate effectively and participate fully in society (Callaghan et al., 2011; Klin et al., 2002). However, diagnosis-defining differences in social-motivation and social-cognition may inhibit autistic children's ability to develop symbolic understanding (Carpenter et al., 2001; Chevallier et al., 2012). Many autistic children experience language delays, often producing their first words around 36–38 months (Anderson et al. 2007; Howlin et al. 2009). As language may provide a vital scaffold for the acquisition of other symbol systems in early neurotypical development (Kirkham et al., 2013; Vygotsky, 1978), early difficulties in this foundational domain may have critical downstream consequences for other communicative domains, including pictures and play. However, existing research has not thoroughly examined inter-domain relationships across multiple symbolic domains in autism spectrum disorder (ASD). Thus, to advance conceptual knowledge of ASD and potentially inform the design of effective communication interventions, this study will (1) investigate how variability in language, and other individual differences, predicts the abilities of 4–11-year-old autistic children in the domains of pictures, play, and social communication and (2) model concurrent interrelations between these symbolic domains.

Language emerges between 12–18 months in neurotypical (NT) children (Tager-Flusberg et al. 2009; Tomasello, 2003b; Zubrick et al. 2007) and is scaffolded by social communication skills such as imitation, gaze following, pointing to direct the attention of others, and joint attention (Bates et al., 1979; Carpenter et al., 1998, 2002; Meltzoff, 1988). Once acquired, language may subsequently mediate the acquisition of symbolic play and pictorial understanding (Kirkham et al., 2013; Vygotsky, 1978). Two longitudinal studies have examined interrelationships between language, symbolic play, and graphic symbols in neurotypical 2–5-year-olds. In children aged 28–42 months, Callaghan and Rankin (2002) identified strong correlations between linguistic, pictorial, and play domains. These interrelationships provide evidence of interdependence across multiple symbolic domains, as in domain-general accounts of symbolic understanding. In children aged 4–5 years old, Kirkham et al. (2013) identified a unidirectional relationship between language and pictures, in addition to relationships between symbolic play and graphic symbolism (that approached statistical significance). These findings suggest that linguistic symbols scaffold acquisition of pictorial domain, but possibly not pictures, providing support for social-cultural accounts of symbolic development (Vygotsky, 1978).

Carter and Hartley (in prep a, see Chapter 2) recently investigated concurrent relationships between symbolic abilities and individual differences in neurotypical development. In a sample of NT 2–5-year-olds, they found that: i) older children, with more developed language skills, exhibited more sophisticated symbolic play skills, ii) greater picture production accuracy was associated with older age, more developed fine motor skills, and observing adult modelling, and iii) higher non-verbal intelligence scores were associated with superior picture comprehension and symbolic play skills. These associations suggest that symbolic domains are predicted by cognitive individual differences, some of which influence multiple domains, and interactions with more symbolically experienced partners may facilitate neurotypical children's picture production skills. Interestingly, language did not contribute to children's use and understanding of pictures or social communication, although there was evidence of a scaffolding role of language for play. The lack of a mediating role of language across non-linguistic symbolic domains contrasts with previous research, and possibly indicates that other variables may have greater influences on graphic representation and social communication as children get older and their skills in these domains improve. Furthermore, they found that superior picture production skills were predicted by sophisticated symbolic play, symbolic play skills were predicted by variability in pictorial understanding and social communication skills, and social communication skills were associated with picture production and symbolic play. These concurrent interrelationships between pictorial, play, and social communication domains indicate that these modules of symbolic development may be underpinned by shared factors. However, no studies to date have investigated inter-domain relationships in autistic children across social communication, language, play, and pictures simultaneously.

Language difficulties in ASD could have implications for the development of pictorial understanding. Considering that picture-based interventions are commonly used to support autistic individuals (Bondy & Frost, 1994), it is surprising that relatively few studies have specifically investigated symbolic understanding of pictures in this population. However, there is mounting evidence that minimally verbal autistic children have a different understanding of symbolic word-picture-object relationships (Hartley & Allen, 2014a, 2014b, 2015a, 2015b; Preissler, 2008). Minimally verbal autistic children often struggle to recognise that information directed at pictures (e.g. verbal labels) relates to their symbolised referents, particularly when iconicity is low (Hartley & Allen, 2015a; Preissler, 2008), and tend to extend labels from pictures based on category-irrelevant features (e.g. colour; Hartley, 2014a). Furthermore, understanding of symbolic word-picture-object relations in ASD may not be informed by inferences about social-communicative intentions underlying pictures (Hartley & Allen, 2014b, 2015c).

Employing a task developed by Callaghan (2000), Hartley et al. (2019) examined whether autistic children use linguistic labels to scaffold their understanding of graphic symbols. Autistic children and neurotypical controls matched on both receptive and expressive language were shown a series of pictures and instructed to choose the corresponding referents from pairs of objects in trials that afforded or inhibited linguistic scaffolding. Verbal mediation of children's picture-object matching was possible when choice objects had different labels (e.g. a cow and a bear), but linguistic scaffolding was not possible when choice objects shared the same basic label (e.g. two different shoes). Both groups performed more accurately during trials where choice referents belonged to distinct linguistic categories, suggesting that their successful deciphering of picture-referent relations was facilitated by verbal scaffolding. If language mediates symbolic understanding of pictures, then children who have profoundly delayed language development are likely to exhibit delays and differences in picture comprehension. Given that language development in ASD is extremely heterogenous (Arunachalam & Luyster, 2016; Tager-Flusberg & Kasari, 2013), there is a pressing need for research to investigate the influence of language, and other individual differences, on children's symbolic understanding of graphic symbols.

Previous research examining the drawing skills of autistic children indicates comparable abilities with neurotypical controls, matched on receptive language ability or mental age, when depicting objects, basic concepts, and emotions (Hartley et al., 2019; Jolley et al., 2013; McCarthy et al., 2018). However, autistic children produce fewer imaginative drawings compared to neurotypical controls (Low et al., 2009) and often struggle to spontaneously depict imaginary entities (e.g. when instructed to draw 'a man with two heads' or 'a door in the roof of a house'; Craig et al., 2001; Leevers & Harris, 1998). When given pre-drawn templates to complete (such as a headless man), autistic children are just as able to depict impossible entities as neurotypical children and children with learning difficulties (Allen, 2009). As relationships between mental age and imaginative drawing abilities were only identified in autistic children, it is possible that receptive language ability may scaffold imaginative drawing processes in ASD (Allen, 2009). If so, individuals with more profound language difficulties might also encounter delays and difficulties in acquiring drawing skills.

Employing a drawing task developed by Kirkham and colleagues (2013), Hartley et al. (2019) examined autistic children's picture production abilities under conditions that varied in difficulty. In 'modelled trials', participants observed the experimenter demonstrating how to draw each unfamiliar object, before producing their own representational drawing. However, in 'unmodelled trials', no demonstrations were provided for participants, making this condition the more challenging of the two. When matched on both language comprehension and language production, the performance of linguistically delayed autistic children was equivalent to neurotypical controls in this task, with greater accuracy in modelled trials compared to unmodelled trials. This indicates that autistic children's object drawing abilities are unimpaired when expectations are based on their linguistic abilities, potentially signalling a relationship between language and picture production skills. If language mediates children's ability to produce representational drawings, then early difficulties in the pictorial domain may diminish as their expressive language skills develop.

Studies examining the relationship between play and language in autistic children demonstrate that individuals with more developed language skills produce more symbolic play acts than those with less developed language skills (Sigman & Ruskin, 1999; Warreyn et al., 2005). While some research demonstrates that both receptive and expressive language difficulties are related to the play of autistic children (Sigman & Ungerer, 1984; Whyte & Owens, 1989), others have found that only superior language production is associated with more developed symbolic play skills in this population (Stanley & Konstantareas, 2007). Autistic children often demonstrate delays and differences in pretending (American Psychiatric Association, 2013) and tend not to spontaneously engage in symbolic play

(Hobson et al. 2013; Jarrold, 2003). Instead, their episodes of play predominantly involve functional play acts (i.e. simple, conventional actions on objects such as pushing a car or building with blocks) and/or restricted, repetitive play acts (e.g. lining up cars or spinning objects). Although research indicates that children's play, language, and social-cognitive abilities are strongly related in ASD (Thiemann-Bourque et al., 2012; Toth et al, 2006), the nature of these relationships is unclear. Given that modelling and/or explicit instruction increases the likelihood of autistic individuals engaging in pretend play (Jarrold, 2003), it is possible that the play-language relationship is mediated through social scaffolding provided by more symbolically competent adults (Lewis, 2003).

Empirical investigation of the relationship between non-verbal social cognitive skills and language in ASD indicates that children's joint attention is a reliable predictor of both language production and language comprehension in ASD (Blume et al., 2020; Siller & Sigman, 2008). Joint attention behaviours involve a triadic sharing of focus between two individuals on an object/event (Bruner, 1975) and enable children to map linguistic input to referents in their immediate environment. Thus, it is regarded as an important scaffolding mechanism in word learning and language development (Tomasello & Farrar, 1986). It is important to acknowledge the multifaceted nature of joint attention and distinguish between specific types, as they could emerge differently, and uniquely contribute to language development (Adamson et al., 2009; Mundy & Jarrold, 2010). Responding to joint attention refers to a child's use of attention-following behaviours, including head turns and eye gaze, to react to social bids for attention from another person (Scaife & Bruner, 1975). Initiation of joint attention refers to a child's use of attention-directing behaviours (e.g. pointing or showing) to orient the attention of a social partner towards an object/event (Mundy et al., 1986). Young autistic children are less responsive to social bids for attention initiated by others (via pointing, verbal language, and gaze shifting) in comparison to neurotypical controls (Chawarska et al., 2012), and rarely attempt to initiate joint attention with others through declarative pointing (Mitchell et al., 2006; Swinkels et al., 2006). While previous research indicates that both RJA and IJA are robust predictors of both language production and language comprehension in ASD (Sigman & McGovern, 2005; Yoder et al., 2015), a recent meta-analysis concluded that RJA is more strongly related to language than other types of joint attention. Considering that language and other symbol systems are cultural conventions that must be acquired from others, RJA may reflect an early propensity for a child to socially orient to others – a necessity for meaningful language learning opportunities (Jones & Klin, 2013; Mundy & Jarrold, 2010).

There is a pressing need for research to address critical gaps in the current ASD literature. In this population, no studies to date have comprehensively investigated concurrent inter-domain relationships across social communication, language, play, and pictures, while accounting for important individual differences (e.g. non-verbal intelligence). Considering that autistic children often exhibit differences in their use of non-verbal social-cognitive skills (e.g. joint attention, imitation, and intention reading; Mundy, 1995), and have difficulty acquiring language (Tager-Flusberg & Kasari, 2013) and other symbol systems, such as pictures (Hartley & Allen, 2015; Preissler, 2008) and pretend play (Stanley & Konstantareas, 2007), their symbolic development could follow one of two patterns. On the one hand, non-linguistic symbol systems may develop independently and be unrelated to linguistic and social-cognitive abilities (Mundy, 1995). This would result in an uneven ability profile whereby a child could have sophisticated play and/or pictorial skills in conjunction with relatively underdeveloped language. On the other hand, symbolic understanding of play and pictures may be acquired via the same route as in neurotypical development, with language and/or social communication mediating learning (Anderson et al., 2007). If this is the case, autistic children's symbolic play and picture abilities would develop at a rate commensurate with expectations based on their current language ability. Empirical investigation of these key issues will contribute to developing theoretical understanding of the relationships between symbolic abilities and individual differences in autistic children, establish how symbolic domains concurrently interrelate in this population, and potentially inform the design and delivery of clinical and educational interventions.

The objectives of the present study were to model: i) concurrent relationships between children's language abilities, other individual differences (e.g. chronological age, fine motor skills, non-verbal intelligence, autism severity), and skills across the domains of pictures, play, and social communication in 4–11-year-old autistic children, and ii) concurrent interrelations between the three non-linguistic symbolic domains. This study follows the same procedure used in Carter and Hartley (in prep a, see Chapter 2). As existing research predominantly fails to acknowledge that young children's comprehension skills outweigh their productive skills in every symbolic domain (Callaghan, 1999), it is essential that both receptive *and* expressive abilities in each domain are measured to comprehensively profile children's symbolic abilities. Picture comprehension was assessed via a picture-object matching task based on Callaghan (2000), which manipulated whether children could utilise verbal labelling to scaffold their performance. Picture production was tested using an object-drawing task based on Kirkham et al. (2013), which required children to draw pictures of unfamiliar target objects with, and without, adult modelling. Symbolic play was assessed via a series of tasks adapted from the Autism Diagnostic Observation Schedule Version 2 (ADOS-2; Lord et al., 2012), which were designed to elicit children's spontaneous, independent play abilities during a free play session, as well as functional and symbolic play skills during the context of a familiar social routine led by an adult (i.e. a birthday party). Measures of social communication (e.g. initiation of joint attention and response to joint attention; use of eye contact; social smiling; and spontaneous giving of items to others) were also tested using several tasks derived from the ADOS-2 (Lord et al., 2012).

Based on previous evidence (e.g. Callaghan & Rankin, 2002; Carter & Hartley, in prep a, see Chapter 2; Hartley et al., 2019; Kirkham et al., 2013), we predicted that positive concurrent interrelations would emerge between measures of individual differences (e.g. chronological age, non-verbal intelligence, fine motor skills) and the symbolic domains of pictures, play and social communication. More developed social communication skills may predict better symbolic understanding, with language also scaffolding performance across non-linguistic pictorial and play symbolic domains (as in NT children; Anderson et al., 2007). Alternatively, symbol systems may develop independently and be unrelated to social communication skills and/or language (due to delays or difficulties; Mundy, 1995). The findings of our study will provide the most detailed account of the relationships between symbolic abilities and individual differences in ASD to date, and potentially reveal inter-domain relationships that can be exploited by interventions in clinical and educational contexts.

Method

Participants

Participants were 27 autistic children (18 males, 9 females; *M* age = 87.07 months, *SD* = 27.79, range = 48–137 months) recruited from specialist schools. All children had normal or corrected-to-normal vision. Receptive and expressive language abilities were measured using the Receptive and Expressive Language modules of the Mullen Scales of Early Learning (Mullen, 1995). Our sample had a mean language comprehension age of 44.11 months (*SD* = 14.59, range = 22–69 months) and a mean language production age of 37.78 months (*SD* = 19.08, range = 3–70 months). Fine motor abilities were measured using the Fine Motor module of the Mullen Scales of Early Learning (Mullen, 1995). The children had a mean score of 44.78 months (*SD* = 11.86, range = 26–68 months). Children were previously diagnosed by a qualified educational or clinical psychologist, using standardised instruments (i.e. Autism Diagnostic Observation Schedule Version 2; Lord et al., 2012 and Autism Diagnostic Interview-Revised; Lord et al., 1994) and expert judgment. Diagnoses were confirmed via the Childhood Autism Rating Scale Second Edition (CARS-2; Schopler et al., 2010), which was completed by each participant's class teacher (*M* score: 37.46, *SD* = 5.21, range = 30–49). Children's non-verbal intellectual abilities were measured using the Leiter-3 (Roid et al., 2013). The mean (age-normed) IQ was 76.93 (*SD* = 13.68; range = 41–107) and the mean Leiter-3 raw score was 55.44 (*SD* = 12.63, range = 36–79). All procedures performed in this study were in accordance with the ethical standards of institutional and national research committees. Informed consent was obtained from caregivers prior to their children's participation.

Materials

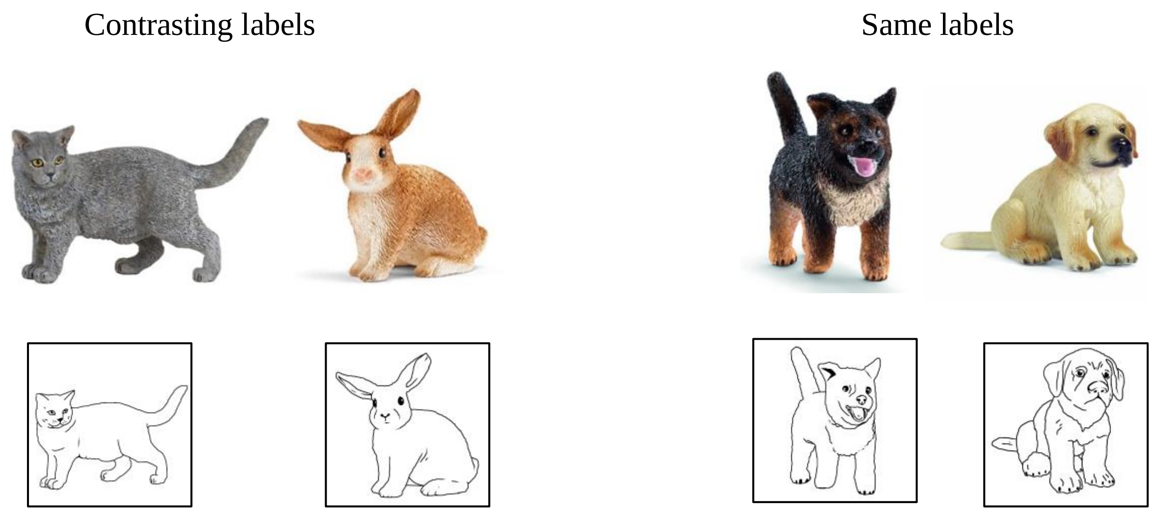
Stimuli and tasks were identical to those described in Carter & Hartley (in prep a, see Chapter 2).

Picture Comprehension

Stimuli included 16 objects and 16 black-and-white line drawings of those objects. All objects were highly familiar and were selected on the basis that most children understand their linguistic labels by 16 months (Fenson et al., 1994). These objects included: cat, bunny, bicycle, motorbike, hairbrush, comb, plastic carrot, plastic banana, two cars, two dogs, two spoons, and two shells. Perceptual similarity of object pairs was controlled for across trial types. For example, in "contrasting labels" trials (i.e. where choice objects belonged to distinct linguistic categories) a standing cat and a sitting bunny were paired together. In "same labels" trials (i.e. where choice objects belonged to the same linguistic categories) a standing dog and a sitting dog were paired together. All pictures used in this study were laminated and measured 5 cm x 5 cm, which is the recommended sizing for Picture Exchange Communication System symbols (PECS; Frost & Bondy, 2002). Examples of paired object stimuli and black-and-white line drawings are displayed in Figure 1. All line drawings had a broadly similar level of detail to ensure that they did not differ markedly in terms of iconicity.

Figure 1

Examples of object stimuli pairs and line drawings used in the picture comprehension task



Picture Production

Stimuli included six different unfamiliar objects, which were divided into two sets (see Figure 2), pencils, and white A5 paper sheets. The novelty of the items ensured that children's responses could not be facilitated by pre-practised drawing routines associated with familiar concepts.

Figure 2

Objects used in the picture production task

Symbolic Play

In the Free Play task, stimuli included a selection of toys: multiple pop-up toy, nesting cups, two animal figures, board book, toy telephone, four pieces of yarn, gold lid, baby doll with open/shut eyes, eight letter blocks, two identical balls, two identical cars, two pairs of plastic utensils, and four plastic plates. Response to Joint Attention was tested using a remote-controlled bunny. In the Birthday Party task, stimuli included a baby doll with open/shut eyes, a plastic plate, a plastic fork, a plastic knife, a plastic cup, a napkin, a jar of play dough, four glue-gun refill ‘candles’, and a small blanket.

Procedure

Participants were tested individually in their own educational settings, accompanied by a familiar adult when required (e.g. key worker, teacher, or teaching assistant). Children were verbally praised for attention and good behaviour while completing the standardised and experimental assessments, which took the form of fun, short “games” administered in separate sessions, on different days. Order of tasks was randomised for each participant.

Language

The Mullen Scales of Early Learning (MSEL; Mullen, 1995) were used to assess

children’s language comprehension and language production, as it benefits from very low language demands (it is suitable for children aged < 1 year) and is frequently administered to autistic children.

The Receptive Language module provided a measure of children’s language comprehension. Children completed tasks which involved auditory discrimination and auditory/motor integration e.g. recognition of familiar names and words, identification of objects and pictures, performing simple actions on request, comprehending questions, testing spatial concepts, and identification of colours and numbers. The Expressive Language module provided a measure of children’s language production. Tasks related to overall productive verbal abilities e.g. producing letter sounds, combining words and gestures, naming simple objects, labelling pictures, use of two-word phrases, use of pronouns, counting, use of short sentences, repetition of word sequences, and verbal analogies. Raw scores for both modules were converted into age equivalents based on the normed guidelines in the assessment handbook.

Non-verbal Intelligence

The Leiter International Performance Scale Third Edition (Leiter-3; Roid et al., 2013) was used to test children’s non-verbal intelligence and provide a measure of IQ. The Leiter-3 was chosen as it can be administered non-verbally and children’s responses can be entirely non-verbal. The Brief Assessment comprises four sub-tests of visualisation and reasoning that, together, provide a reliable measure of the respondent’s IQ. These sub-tests assess children’s ability to match colours, pictures, and shapes, identify specific features of pictures, mentally rotate images, and to infer/complete patterns. Participants’ raw scores (possible range: 0–152) and IQ scores (possible range 0–170) were calculated as per the guidelines in the assessment handbook.

Fine Motor Skills

The Fine Motor module of the MSEL (Mullen, 1995) was administered to provide a measure of children's fine motor skills. Children completed tasks which involved motor planning and motor control. Some activities required bilateral manipulation (e.g. unscrewing/screwing a nut and bolt, threading beads, folding, and cutting) and others involved unilateral manipulation (e.g. stacking blocks, inserting pennies in slots, and drawing/writing). Raw scores were converted into age equivalents based on the normed guidelines in the assessment handbook.

Symbolic Play

Tasks derived from the Autism Diagnostic Observation Schedule Version 2 (ADOS-2; Lord et al., 2012) provided a measure of children's symbolic play. The ADOS-2 is a semi-structured, standardised assessment of communication, social interaction, play, and restricted and repetitive behaviours. The following tasks were administered by a trained experimenter, as per the guidelines in the Module 1 manual: Free Play and Birthday Party. An adapted scoring system was created to allow for in vivo scoring (see Appendix A).

Free Play. This task provided an opportunity for children to independently interact with a selection of toys arranged on a table in front of them. Initially, the experimenter directed the child's attention to the various toys ("Look at these toys. You can play with them.") Children were allowed to play without interruption for 3 minutes. If the child did not engage in any play during this time, or played exclusively with one toy in a limited and/or repetitive manner, the experimenter re-directed the child's attention to the various toys ("What can you do with these toys?"). If necessary, the experimenter also removed the main preoccupation. If the child had not exhibited any spontaneous pretend play after 3 minutes, the experimenter instructed the child to "Look…" and modelled simple pretend play (e.g. feeding the doll using a fork) for them to copy ("You do it."). Children were then allowed to play independently for a further 2–3 minutes.

During the Free Play task, the experimenter recorded which toys the child interacted with and categorised each interaction/play sequence using the following three categories: i) spontaneous pretend play, ii) functional play, iii) limited, repetitive play or no play. If a child demonstrated one or more instances of spontaneous pretend play (e.g. giving a doll a drink from a cup or pretending to talk on a toy telephone), they received two points. Instances of spontaneous pretend play which involved object substitution (i.e. using one object to stand for another) and/or attribution of agency (e.g. involving a figure or doll in an action) were noted. One or more observed instances of object substitution (e.g. pretending yarn is spaghetti) received an additional point. One or more observed instances of attributing agency (e.g. moving a figure or doll as if it is capable of action) scored an additional point. If a child did not demonstrate any instances of spontaneous pretend play, but exhibited functional play (e.g. stacking nesting cups or interacting with cause-and-effect toys), they achieved a total score of one. Limited, repetitive play (e.g. mouthing or banging objects) or no play attracted a score of zero. Total 'Free Play' scores could range from 0–4. The experimenter also noted whether adult intervention/modelling was required (0 = no modelling required; 1 = modelling required), and if so, whether the child imitated the modelled pretend play (0 = imitation; 1 = no imitation). If the child demonstrated an unusual sensory interest in play materials, such as flicking the doll's eyelids, this was also noted (0 = no observed instances of unusual sensory interest; 1 = one or more observed instances of unusual sensory interest).

Birthday Party. This task assessed children's functional and symbolic play skills in the context of a familiar social routine. The experimenter observed how children engaged with the doll/other materials, their degree of spontaneity, and evaluated whether the children understood the script of the party scenario. The task involved seven sequential stages:

Putting Candles on Cake. First, the experimenter directed the child's attention to the baby doll ("Look, here's Baby!) and explained, "It's Baby's birthday, let's have a birthday party." Next, the experimenter patted the play dough on a plate ("Here's the birthday cake…"), placed a 'candle' on the cake, handed one candle to the child and left the other two in reach ("Here are the candles."). If the child put the candles on the cake, they scored one point.

Singing Happy Birthday. The experimenter then 'lit' the candles with a pretend match, shook it out saying "Hot" and asked, "What should we do now?" If the child did not respond, the experimenter said, "Let's sing Happy Birthday!" and started to sing. If the child sang, they scored one point.

Blowing out Candles. If the child did not spontaneously blow out the candles or help the doll to do so, the experimenter prompted, "Let's blow out the candles!" and then asked, i) "What's next?" (ii) opened their mouth (iii) put mouth into a blowing position (iv) blew out the candles. The experimenter looked at the child with anticipation at each step. If the child helped the baby to blow out the candles using the doll as an independent agent, they achieved a score of three for this item. If the child blew out the candles but did not use the doll as an independent agent, they scored two points. If the child imitated blowing out the candles after explicit demonstration, they scored one point. If the child did not blow out the candles, they received zero points.

Feeding Baby. The experimenter then gave the fork to the child and said "Baby's hungry." If the child fed the baby immediately, they scored three points. If the child fed the baby after a second prompt ("Baby wants birthday cake…"), they scored two points. If the child fed the baby after explicit demonstration, they scored one point. If the child did not feed the baby, they scored zero points.

Giving Baby a Drink. Th experimenter prompted "Baby's thirsty." If the child used the nearby cup to give the baby a drink, they scored one point. If the child did not give the doll a drink, the experimenter pretended to pour some juice and give the doll a drink. If the child gave the baby a drink after this explicit demonstration, they scored one point. If the child did not give the baby a drink, they scored zero points.

Cleaning Up. The experimenter knocked over the cup, saying “Oh no, I spilled the drink! What should we do?” If the child immediately cleaned up (either using the nearby napkin, using another item as if it were a napkin or simply pretending to hold a napkin), they scored three points. If the child cleaned up after a second prompt (“Can you help clean up?”), they scored two points. If the child cleaned up after being handed the napkin, they scored one point. If the child still did not engage, the experimenter pretended to wipe up, and the child scored zero points for this item.

Putting Baby to Bed. The experimenter explained, “The birthday party has finished. Baby is tired. Can you help?” If the child immediately used the blanket (placed within reach on the table) to cover the baby, they achieved a score of three points. If the child used the blanket to cover the baby after the second prompt (“Baby is tired, time for bed…”), they scored two points. If the child covered the baby with the blanket, after being handed it, they scored one point. If the child did not cover the doll with the blanket, the experimenter performed the action and the child scored zero points for this item. Total scores for the Birthday Party task ranged from 0–15.

Videos from 10% of participants were independently coded by a second rater who was naïve to the participants’ details and the study’s hypotheses. Interrater reliability was calculated for each of the symbolic play tasks. There was complete agreement (k = 1.00, p = .008) on each individual aspect of the symbolic play tasks (i.e. Free Play and Birthday Party).

Social Communication

Measures of social communication were based on aspects of the Autism Diagnostic Observation Schedule Version 2 (Lord et al., 2012). The following tasks were administered by a trained experimenter, during the Free Play task described above, as per the guidelines in the Module 1 manual: Response to Name, Response to Joint Attention and Responsive Social

Smile. The experimenter also noted whether the child demonstrated unusual eye contact (0 = unusual; 1 = not unusual). During both the Free Play and Birthday tasks, the experimenter also noted whether the child spontaneously gave items to the experimenter (0 = no observed instances of giving; 1 = one or more observed instances of giving), or spontaneously initiated joint attention (2 = clear attempt to direct experimenter's attention towards a distal referent, and child looks back at the experimenter AND the referent; 1 = attempt to direct experimenter's attention towards a distal referent, but child does not look back at experimenter OR referent; 0 = no attempts to direct experimenter's attention towards a distal referent). An adapted scoring system was created to allow for in vivo scoring (see Appendix B).

Response to Name. This task probed whether the child responded to their name being called by the experimenter (or a familiar adult). While the child was engaged with a toy, or another activity of interest, and looking away, the experimenter moved behind and to the side of the child and called their name. If the child did not turn and make eye contact, the experimenter gave the child four more opportunities to respond. If the child looked at the experimenter and made eye contact after the first or second press, the child scored three points. If the child made an appropriate vocal response (e.g. "What?, "Huh?", "Yes?") but did not look, the experimenter re-administered this measure later. If the child looked towards the experimenter after the third or fourth press, they scored two points. If the child did not make eye contact, but shifted gaze briefly, or looked towards an interesting vocalisation, they scored one point.

Response to Joint Attention. This task examined whether the child responded to the experimenter's gaze shift/head movement to locate a target object that was concealed and out of reach. The experimenter initiated this activity when the child was already engrossed with another toy. Importantly, the experimenter never verbally referred to the toy at any point during this task.

First, the experimenter established the child's attention by calling, "[child's name], look!", then overtly shifted their gaze towards the referent (bunny), then back to the child. If the child followed the experimenter's gaze, the experimenter activated the toy and the child scored three points. If the child did not follow the experimenter's gaze, the experimenter called, "[child's name], look at THAT!", then overtly shifted their gaze towards the referent, then back to the child up to two times. If the child followed the experimenter's gaze on either press, the experimenter activated the toy and the child scored two points. If the child did not follow the experimenter's gaze, the experimenter called, "[child's name], look at THAT!", then pointed at the referent, overtly shifted their gaze towards the bunny, then back to the child up to two times. If the child followed the experimenter's point on either press, the experimenter activated the toy and the child scored one point. If the child did not follow the experimenter's point, the experimenter activated the toy for 5 seconds. If the child looked at the referent when activated, they scored one point, and the task ended. If the child did not look at the referent when activated, the experimenter activated the toy for a further 5 seconds. If the child still did not look at the referent, they scored zero points.

Responsive Social Smile. The objective of this task was to identify whether the child smiled in response to a purely social overture (laughter did not count). The experimenter initiated this activity when the child was not already smiling.

First, the experimenter established the child's attention by calling their name or using a toy, and said, "Look at you!" while smiling. If the child immediately smiled in response to the first or second smile, they scored three points. If the child partially smiled after the first or second smile, they scored two points. If the child did not respond, the experimenter allowed the child to continue with their activity for a moment, and then repeated the initial prompt. If the child smiled back after this additional press, they scored two points. If the child did not smile at the experimenter, the experimenter asked the teacher, “Can you show me how you get [child’s name] to smile without touching him/her?” If the child smiled at the familiar adult, the child scored two points, and the activity ended. If the child did not smile, the experimenter asked the familiar adult to touch the child in order to evoke a smile. If the child smiled in response to physical contact or repeated physical action, they achieved a score of one point. If the child never smiled in response to another person, they scored zero points for this item.

Videos from 10% of participants were independently coded by a second rater who was naïve to the participants’ details and the hypotheses in this study. Interrater reliability was calculated for each of the social-communication tasks. There was complete agreement on Response to Name (k = 1.00; p = .008), Response to Joint Attention (k = 1.00; p = .008), Responsive Social Smile (k = 1.00; p < .001), and Eye Contact (k = 1.00; p = .008). Interrater reliability was substantial for Giving (k = 0.70; p = .053) and Spontaneous Initiation of Joint Attention (k = 0.75; p = .013).

Picture Comprehension

A picture-object matching task (Callaghan, 2000) was used to assess children’s picture comprehension. Pictures and referent objects were used as stimuli in this task. Children were presented with a black-and-white line drawing of an object for 4s. The experimenter pointed to the depicted object and instructed the child to “look at this picture!” The drawing was then removed from view, and two choice objects were presented – a target and a foil – approximately 30cm apart and equidistant from the participant. The experimenter asked children to “find the one in the picture.”

There were two trial types: contrasting labels (CL) and same labels (SL). Children completed 16 trials in total (8 of each type). In CL trials, the choice objects were familiar and belonged to distinct linguistic categories (cat, bunny, bicycle, motorbike, hairbrush, comb, plastic carrot, plastic banana). Crucially, children's picture-object matching in CL trials could be scaffolded by verbally labelling the picture and matching to a referent object with the same label. In SL trials, the choice objects were familiar but belonged to the same linguistic categories (two cars, two dogs, two spoons, two shells). Although, the items in SL trials were familiar, children's picture-object matching could not be scaffolded by verbal labelling; both potential referents had the same label, and therefore could only be discriminated based on resemblance to the picture. Perceptual similarity of object pairs was controlled for across trial types. The order of trial types was randomised for each participant, subject to the criterion that no more than two trials of the same type (CL or SL) were presented consecutively.

In accordance with standard coding criteria (e.g. Allen et al., 2015; Hartley & Allen, 2015a; Preissler, 2008), only intentional responses were coded (e.g. giving or sliding an object to the experimenter, pointing to, or picking up and showing the experimenter an item). For example, if a child manually explored the foil object having already clearly indicated that the target was the depicted referent via pointing or vocalisation, their response was coded as correct. If children correctly identified the depicted target object, they scored one for that trial. If they incorrectly identified the foil, they scored zero. Total scores could range from 0–16 and performance on each trial type could range from 0–8.

Picture Production

An object-drawing task based on Kirkham et al. (2013) was used to assess children's picture production. Children were provided with a pencil and paper and instructed to draw six unfamiliar objects that were presented individually. Objects were selected on the basis that they could be drawn using circles and/or lines, as these tend to be the first drawing units that appear in children's early drawing attempts (Levin & Bus, 2003). Therefore, failure to produce an accurate representation of each object in the task should not be attributable to a motor production difficulty (Callaghan & Rankin, 2002).

For three objects, the experimenter modelled drawing a simple picture of the target object before the child created their drawing (Modelled Trials). The experimenter instructed participants to "watch carefully" while they were drawing and then highlighted the symbolic relationship between their drawing and the target object ("this drawing shows this object"). The experimenter's drawing was then removed before the child started drawing ("now, can you draw this object?"). These trials enabled us to assess children's picture production abilities when receiving explicit adult scaffolding. For the other three objects, the experimenter did not provide a demonstration before children created their drawings (Unmodelled Trials). This manipulation allowed us to gain a more precise account of children's picture production abilities under conditions that varied in difficulty. Participants were randomly assigned one of four different presentation orders that varied in terms of the objects allocated to Modelled and Unmodelled Trials and the order of trial types. No more than two trials of the same type were presented consecutively, and children were given up to 5 minutes to produce each drawing.

Every drawing was coded by the first experimenter and an independent rater with expertise in the field who was blind to the study's objectives, the participant's details (e.g. their age, diagnosis, etc), and whether the trial was Modelled or Unmodelled. The drawings were presented to the independent rater individually, and they were asked them to identify which of the 6 possible objects the child had depicted. If the rater matched the drawing to the correct referent object, children scored 1 (an incorrect match scored 0). Interrater reliability was very high (k = .97, p < .001).

At another time, as part of the overall battery of assessments, children also completed a Free Draw control task, to determine if they were capable of independently drawing representational pictures composed of circles and lines. Children were provided with a pencil and paper (for a maximum of 5 minutes) and instructed to "Draw a picture. You can draw anything you want to.” Every drawing was coded by the first experimenter and an independent rater with expertise in the field who was naïve to the participants’ details and the hypotheses in this study. Both raters were required to judge whether it was possible to: i) recognise what, if anything, was represented (0 = scribble/accidental markings; 1 = controlled, representational markings), ii) identify circles (0 = no circles; 1 = one or more circles), and iii) identify lines (0 = no lines; 1 = one or more lines). Interrater reliability was very high (Representational: $k = 0.93$; $p < .001$; Circles: $k = 1.00$; $p < .001$; Lines: $k = 1.00$; $p < .001$).

Results

Examining Individual Differences Within Domains

To investigate the influence of individual differences within domains, data generated by the battery of standardised assessments and experimental tasks were analysed via generalised linear mixed effects models and linear mixed effects models using the glmer and lmer functions from the lme4 package in R (Bates et al., 2015), or multiple regression models. Receptive Language, Expressive Language and Fine Motor Skills were coded as the participant’s age equivalent score on the corresponding modules of the Mullen Scales of Early Learning. Non-verbal Intelligence was coded as the participant’s raw score on the Leiter-3. CARS Score was coded as the participant’s total score on the CARS-2. Chronological Age was coded as the participant’s age in months.

For each analysis, we started with a baseline model containing only by-participant and by-item random intercepts to account for variation across participants and stimuli. Fixed effects were added individually, and we tested whether their inclusion significantly improved predictive fit. Please refer to Appendix C for full details of the model building processes for all analyses.

Picture Comprehension

Trial Number was coded 1–16, based on the order of trial administration, and was tested as a fixed effect to rule out practice effects. Accuracy was coded as 0 (incorrect) and 1 (correct). The mean score in the Contrasting Labels Condition was 0.97 (*SD* = 0.42) and the mean score in the Same Labels Condition was 0.92 (*SD* = 1.13). The likelihood of responding correctly by chance was 50%. Trial Type was contrast coded as -0.5 (Contrasting Labels Condition) and +0.5 (Same Labels Condition). The analysis included 432 trials in total.

A model containing Trial Type, Fine Motor Skills, and CARS Score provided the best fit to the observed data (see Table 1). These results suggest that increased likelihood of correctly identifying the depicted target object was associated with responding in contrasting labels trials (rather than same labels trials), more developed fine motor skills, and lower CARS scores.

Table 1

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of autistic children's picture comprehension accuracy, predicted by Trial Type, Fine Motor Skills, and CARS score

Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	4.46	2.35	1.90	.058
Trial Type	1.16	0.50	2.33	.020*
Fine Motor Skills	0.08	0.04	2.25	.025*
CARS Score	-0.12	0.06	-2.03	.043*
	AIC	BIC	logLik	deviance
	166.4	190.9	-77.2	154.4

Picture Production

Trial Number was coded 1–6, based on the order of trial administration, and was tested as a fixed effect to rule out practice effects. Accuracy was coded as 0 (incorrect) and 1 (correct). The mean score in the Unmodelled Trials Condition was 0.52 (SD = 1.03) and the mean score in the Modelled Trials Condition was 0.67 (SD = 1.06). Trial Type was contrast coded as -0.5 (Unmodelled Trials Condition) and +0.5 (Modelled Trials Condition). The analysis included 162 trials in total.

A model containing Trial Type and Fine Motor Skills provided the best fit to our observed data (see Table 2). These results suggest that increased likelihood of generating representational drawings that could be matched to their intended referents was associated with responding in modelled trials (rather than unmodelled trials) and more developed fine motor skills.

Table 2

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of autistic children's picture production accuracy, predicted by Trial Type and Fine Motor Skills

Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	-7.74	2.40	-3.22	.001*
Trial Type	1.75	0.59	2.95	.003*
Fine Motor Skills	0.20	0.05	3.89	< .001*
	AIC	BIC	logLik	deviance
	151.6	167.0	-70.8	141.6

Free Play

Based on the participant's raw scores on the adapted ADOS Free Play task, Total Toys was coded 0–13 (*M* = 4.63, *SD* = 1.42), Highest Level of Play was coded 0–2 (*M* = 1.19, *SD* = 0.62), and all of the following measures were coded 0–1: Uses Toys as Agents (*M* = 0.22, *SD* = 0.42), Object Substitution (*M* = 0.19, *SD* = 0.40), Unusual Sensory Interest (*M* = 0.41, *SD* = 0.50), Adult Intervention Required (*M* = 0.81, *SD* = 0.40) and Imitates Modelled Play (*M* = 0.37, *SD* = 0.49).

As participants contributed only one data point each, relationships between measures of play and participant individual differences were explored via multiple regression modelling rather than mixed-effects modelling, with comparisons drawn between models of varying complexity to identify the most parsimonious and best-fitting explanation for each dependent variable. Each analysis started by entering all participant demographic features simultaneously (Chronological Age, Receptive Language, Expressive Language, Fine Motor Skills, Non-verbal Intelligence and CARS Score). The second model contained only the predictors identified as significant in Model 1. A model comparison was conducted to confirm that there was no significant decrease in fit between Model 1 and Model 2. Then, in Model 3, all the non-dependent play measures were entered simultaneously alongside the significant demographic predictors. Where no significant predictors were identified in Model 1, the non-dependent play measures were entered in Model 2 instead. In Model 4, all the non-significant play measures were removed, and a model comparison was conducted between Model 3 and Model 4 to confirm that there was no significant decrease in fit. Thus, for most analyses, Model 4 represents the most parsimonious and best-fitting explanation for each dependent variable (or Model 3 if no significant predictors were identified in Model 1).

Total Toys

Total Toys was best predicted by Highest Level of Play (β = 1.67 p < .001), F(1, 25) = 29.23, p < .001, adjusted R^2 = 0.52, suggesting that playing with a higher number of toys was associated with increased likelihood of engaging in more sophisticated play.

Highest Level of Play

Highest Level of Play was best predicted by Total Toys (β = 0.21 p = .003) and Uses Toys as Agents (β = 0.63 p = .008), F(2, 24) = 23.19, p < .001, adjusted R^2 = 0.63. These results suggest that engaging in more sophisticated play was associated with an increased likelihood of playing with a higher number of toys and using toys as agents.

Uses Toys as Agents

Uses Toys as Agents was best predicted by Highest Level of Play (β = 0.17, p = .034) and Object Substitution (β = 0.79, p < .001), F(2, 24) = 59.08, p < .001, adjusted R^2 = 0.82. These results suggest that using toys as agents was associated with increased likelihood of engaging in more sophisticated play and increased instances of object substitution.

Object Substitution

Object Substitution was best predicted by Uses Toys as Agents (β = 0.65, p < .001) and Adult Intervention Required (β = -0.29, p = .012), F(2, 24) = 64.52, p < .001, adjusted R^2 = 0.83. These results suggest that substituting toys to stand for something else was associated with decreased likelihood of requiring adult intervention during play, and increased likelihood of using toys as agents.

Unusual Sensory Interest

Unusual Sensory Interest was best predicted by Chronological Age (β = -0.01, p = .008), Model 2 F(1, 25) = 8.20, p = .008, adjusted R^2 = 0.22, suggesting that children's likelihood of exhibiting unusual sensory interests increased as chronological age decreased.

Adult Intervention Required

Adult Intervention Required was best predicted by Chronological Age (β = -0.01, p < .001), Non-verbal Intelligence (β = 0.01, p = .007) and Object Substitution (β = -0.69, p < .001), F(3, 23) = 25.27, p < .001, adjusted R^2 = 0.74. These results suggest that requiring adult intervention was associated with lower chronological age, higher Leiter-3 raw scores, and reduced likelihood of object substitution during play.

Imitates Modelled Play

Imitates Modelled Play was best predicted by Highest Level of Play (β = -0.38, p = .011), F(1, 25) = 7.63, p =.011, adjusted R^2 = 0.20, suggesting that propensity to imitate modelled play was associated with less sophisticated play.

Birthday Party

Based on the maximum number of points available for the separate trials, pass/fail variables were coded 0–1: Putting Candles on Cake, Singing Happy Birthday, and Giving Baby a Drink, and experimenter-scaffolded variables were coded 0–3: Blowing out Candles, Feeding Baby, Cleaning Up, and Putting Baby to Bed. Relationships between these measures of play and participant individual differences were explored via generalised linear mixed-effects modelling for 0–1 trials, and linear mixed-effects modelling for 0–3 trials. Trial Type was coded as either 0–1 or 0–3, based on the maximum number of points available for the separate trials. The maximum total score for the Birthday Party task was 15 (M = 10.39, SD = 1.95). The analysis included 189 trials in total.

0–1 Trials (Putting Candles on Cake, Singing Happy Birthday, Giving Baby a Drink)

A model containing CARS Score provided the best fit to the observed data (see Table 3), suggesting that children who had higher CARS scores were more likely to score a 1 on 0–1 Birthday Party trials.

Table 3

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of autistic children's performance on 0–1 trials, predicted by CARS score

Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	-2.99	3.68	-0.81	.417
CARS Score	0.17	0.09	1.90	.058
	AIC	BIC	logLik	deviance
	56.6	66.2	-24.3	48.6

0–3 Trials (Blowing out Candles, Feeding Baby, Cleaning Up, and Putting Baby to Bed)

A model containing Fine Motor Skills provided the best fit to our observed data (see Table 4), suggesting that increased likelihood of attaining higher scores in 0–3 Birthday Party trials was associated more developed fine motor skills.

Table 4

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of autistic children's performance on 0–3 trials, predicted by Fine Motor Skills

Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	0.77	0.38	2.05	.059
Fine Motor Skills	0.03	0.01	4.80	< .001
	AIC	BIC	logLik	deviance
	252.2	265.6	-121.1	242.2

Social Communication

Based on the participant's raw score on the corresponding modules of the adapted ADOS social-communication tasks, Response to Name (M = 2.22, SD = 0.93), Response to

Joint Attention (*M* = 1.89, *SD* = 0.70), and Social Smile (*M* = 1.52, *SD* = 0.94) were coded 0–3, and Eye Contact (*M* = 0.15, *SD* = 0.36), Giving (*M* = 0.07, *SD* = 0.27), and Initiation of Joint Attention (*M* = 0.26, *SD* = 0.59) were coded 0–1.

As participants contributed only one data point each, relationships between measures of social communication and participant individual differences were explored via multiple regression modelling rather than mixed-effects modelling, with comparisons drawn between models of varying complexity in order to identify the most parsimonious and best-fitting explanation for each dependent variable.

We entered all of the social communication measures together in the first block, and then subsequently added each of the demographic variables in the second block. By taking this approach, which is comparable to the regression analyses conducted by Kirkham et al. (2013), we were able to discretely investigate the relationships between Response to Name, Response to Joint Attention, Social Smile, Eye Contact, Giving and Initiation of Joint Attention, and then subsequently investigate how these relationships are impacted by Chronological Age, Receptive Language, Expressive Language, Fine Motor Skills, Non-verbal Intelligence and CARS Score.

Response to Name

Response to Name was best predicted by Response to Joint Attention (β = 0.91 p < .001), Social Smile (β = 0.45, p = .003) and Expressive Language (β = -0.02, p = .034), $F(3, 23) = 15.16$, p < .001, adjusted R^2 = 0.62. These results suggest that likelihood of responsive social smiling was associated with higher scores on the Response to Joint Attention and Social Smile tasks, and less developed expressive language skills.

Response to Joint Attention

Response to Joint Attention was best predicted by Response to Name (β = 0.44, p < .001) and Expressive Language (β = 0.02, p = .002), $F(2, 24) = 22.06$, p < .001, adjusted R^2 =

0.62. These results suggest that increased likelihood of following the examiner's gaze toward a specific referent was associated with higher Response to Name scores and more developed expressive language skills.

Social Smile

Social Smile was best predicted by Response to Name (β = 0.45, p = .001) and Chronological Age (β = 0.02, p < .001), $F(2, 24) = 23.16$, p < .001, adjusted R^2 = 0.63. These results suggest that increased likelihood of responsive social smiling was associated with higher Response to Name scores and increased chronological age.

Eye Contact

Eye Contact was best predicted by Initiation of Joint Attention (β = 0.33 p = .006) and Chronological Age (β = -0.01, p = .009), $F(2, 24) = 6.32$, p = .006, adjusted R^2 = 0.29. These results suggest that increased likelihood of making appropriate eye contact with the examiner was associated with higher Initiation of Joint Attention scores and younger children.

Giving

Giving was not predicted by any of the social skills or individual differences across participants.

Initiation of Joint Attention

Initiation of Joint Attention was best predicted by Social Smile (β = 0.32, p = .007), $F(1, 25) = 8.79$, p = .007, adjusted R^2 = 0.23, suggesting that increased likelihood of spontaneously attempting to direct the examiner's attention to a distal referent was associated with higher Social Smile scores.

Examining Interrelations Between Play, Pictures, and Social Communication

To examine interrelations between symbolic domains, data generated by the battery of standardised assessments and experimental tasks were analysed via generalised linear mixed effects models and linear mixed effects models using the glmer and lmer functions from the lme4 package in R (Bates et al., 2015), or via multiple regression models. All models contained by-participant and by-item random intercepts to account for variation across participants and stimuli. Fine Motor Skills were coded as the participant's age equivalent score on the corresponding modules of the Mullen Scales of Early Learning. CARS Score was coded as the participant's total score on the CARS-2. Free Play and Birthday Party were coded as the participant's raw scores on the adapted ADOS symbolic play tasks. Picture Comprehension was coded as the participant's raw score on the Picture Comprehension task, and both trial types (Same Labels and Contrasting Labels) were coded as 0–3. Picture Production was coded as the participant's raw score on the Picture Production task, and both trial types (Modelled and Unmodelled) were coded as 0–3. Social Communication was coded as the participant's raw score on the adapted ADOS social-communication task, and each individual trial was coded as either 0–3 (Response to Name, Response to Joint Attention, Social Smile) or 0–1 (Eye Contact, Giving and Initiation of Joint Attention). Independent Drawing was coded as participant's raw score on the Free Draw Task.

For each analysis, we started with a baseline model containing the variables that were identified as significant in the preceding analyses for each task. Fixed effects were added individually, and we tested whether their inclusion significantly improved predictive fit. Please refer to Appendix C for full details of the model building processes for all analyses.

Picture Comprehension

This analysis included 432 trials in total. A model containing Trial Type, Fine Motor Skills, CARS Score, Free Play, and Unmodelled Trials as fixed effects, provided the best fit to our observed data (see Table 5). In addition to the effects of Trial Type, Fine Motor Skills, and CARS Score described in the preceding individual differences analyses, these results suggest that increased likelihood of correctly identifying the depicted target object was associated with more developed play skills and higher scores on unmodelled picture production trials

Table 5

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of autistic children's picture comprehension accuracy, predicted by Trial Type, Fine Motor Skills, CARS Score, Free Play, and Unmodelled Trials

Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	6.73	2.34	2.88	.004
Trial Type	1.17	0.50	2.34	.019
Fine Motor Skills	0.09	0.04	2.30	.022
CARS Score	-0.24	0.07	-3.19	.001
Free Play	0.82	0.36	2.32	.021
Unmodelled Trials	0.63	0.35	1.81	.069
	AIC	BIC	logLik	deviance
	160.1	192.7	-72.1	144.1

Picture Production

This analysis included 162 trials in total. The baseline model, containing Trial Type and Fine Motor Skills as fixed effects, provides the best fit to our observed data (see Table 2, p. 133).

Free Play

Based on the participant's raw scores on the adapted ADOS Free Play task, Total Toys was coded 0–13, Highest Level of Play was coded 0–2, and all of the following measures were coded 0–1: Uses Toys as Agents, Object Substitution, Unusual Sensory Interest, Adult Intervention Required and Imitates Modelled Play. The analysis included 27 trials in total. Interrelations between measures of play, pictures and social communication were explored via multiple regression modelling, with comparisons drawn between models of varying complexity to identify the most parsimonious and best-fitting explanation for each dependent variable.

Total Toys

Total Toys was best predicted by Highest Level of Play (β = 1.58 p < .001) and Modelled Trials (β = 0.32, p = .072) which approached significance, $F(2, 24) = 17.86$, p < .001, adjusted R^2 = 0.56. In addition to the effects of Highest Level of Play, these results suggest that children who achieved higher scores on modelled picture production trials were more likely to interact with a higher number of toys compared to children with lower scores.

Highest Level of Play

Highest Level of Play was best predicted by Total Toys, (β = 0.20 p = .003), Uses Toys as Agents (β = 0.70 p = .003) and Giving (β = 0.54 6, p = .055) which was borderline significant, $F(3, 23) = 18.81$, p < .001, adjusted R^2 = 0.67. In addition to the effects of Total Toys and Uses Toys as Agents described in the preceding individual differences analyses, these results suggest that children who exhibited more sophisticated symbolic play skills during independent free play were more likely to spontaneously give items to the experimenter than children with less developed symbolic play skills.

Uses Toys as Agents

None of the models significantly differed in fit when compared with the baseline model, which already contained Highest Level of Play and Object Substitution.

Unusual Sensory Interest

Unusual Sensory Interest was best predicted by Chronological Age (β = -0.01 p = .028) and Response to Name (β = -0.18, p = .064) which approached significance, $F(2, 24)$ = 6.44, p = .006, adjusted R^2 = 0.30. In addition to the effect of Chronological Age, these results suggest that children's likelihood of exhibiting unusual sensory interests increased as Response to Name score decreased.

Adult Intervention Required

Adult Intervention Required was best predicted by Chronological Age (β = -0.01, p = .002), Non-verbal Intelligence (β = 0.02, p = .005) and Contrasting Labels Trials (β = -0.13, p = .036), F(3, 23) = 5.66, p = .005, adjusted R^2 = 0.35. In addition to the effects of Chronological Age and Non-verbal Intelligence, these results suggest that children who achieved higher scores on Contrasting Labels trials were less likely to require adult intervention during free play than children with lower scores.

Imitates Modelled Play

Imitates Modelled Play was best predicted by Highest Level of Play (β = -0.41 p = .002), Picture Comprehension (β = -0.11 p = .004), Eye Contact (β = -0.56 p = .006) and Response to Name (β = 0.15, p = .060) which was borderline significant, F(4, 22) = 8.95, p < .001, adjusted R^2 = 0.55. In addition to the effect of Highest Level of Play, these results suggest that as children's imitation of play actions modelled by the experimenter increased, Picture Comprehension scores and Eye Contact scores decreased, while Response to Name scores increased.

Birthday Party

This analysis included 189 trials in total.

0–1 Trials (Putting Candles on Cake, Singing Happy Birthday, Giving Baby a Drink)

The baseline model, containing only CARS Score as a fixed effect, provides the best fit to our observed data (see Table 3).

0–3 Trials (Blowing out Candles, Feeding Baby, Cleaning Up, and Putting Baby to Bed)

A model containing Fine Motor Skills, Free Play and Eye Contact as fixed effects provided the best fit to our observed data (see Table 6). Increased likelihood of attaining higher scores in the 0–3 Birthday Party trials was associated with more developed fine motor skills, more developed play skills, and higher Eye Contact scores.

Table 6

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of autistic children's accuracy on 0–1 trials, predicted by Fine Motor Skills, Free Play, and Eye Contact

Fixed effects	Estimated coefficient	Std. error	*t*	Pr(>|z|)
(Intercept)	0.36	0.38	0.95	.359
Fine Motor Skills	0.03	0.01	5.50	< .001
Free Play	0.15	0.05	3.02	.003
Eye Contact	0.44	0.18	2.43	.017
	AIC	BIC	logLik	deviance
	242.7	261.4	-114.3	228.7

Social Communication

Interrelations between measures of social communication, play, and pictures were explored via multiple regression modelling, with comparisons drawn between models of varying complexity to identify the most parsimonious and best-fitting explanation for each dependent variable. For all social communication dependent variables (Response to Name, Response to Joint Attention, Social Smile, Eye Contact, Giving, and Initiation of Joint Attention), the inclusion of additional fixed effects did not significantly improve predictive fit when compared with the baseline models.

Discussion

This study examined (1) how variability in language, and other individual differences, predicted the abilities of 4–11-year-old autistic children in the domains of pictures, play, and social communication and (2) modelled concurrent interrelations between non-linguistic symbolic domains. When we investigated the influence of individual differences within domains, we found that trial type and fine motor skills predicted children's picture comprehension and picture production accuracy. We also identified that age, autism severity, and fine motor skills were associated with more sophisticated symbolic play. Furthermore, expressive language and age predicted children's social communication skills. When we examined interrelations between the non-linguistic symbolic domains, we found that superior picture comprehension abilities were associated with more sophisticated symbolic play and picture production skills. Superior picture production was also observed when adult modelling was provided, thus indicating a social communicative effect. We also identified that symbolic play skills were predicted by variability in pictorial abilities and social communication skills. However, social communication abilities were not predicted by pictorial or play skills.

Children's picture comprehension accuracy was significantly more accurate in Contrasting Labels trials, and greater accuracy was predicted by more developed fine motor skills. As our picture-object matching task specifically manipulated the availability of linguistic scaffolding, an effect of trial type suggests that our participants benefitted from linguistic scaffolding to correctly identify depicted target objects. These findings are in alignment with Hartley et al. (2019), who found that autistic children matched pictures and objects more accurately when linguistic scaffolding was available (also see Callaghan, 2000). It is possible that children with more developed fine motor skills engage with pictures more frequently in their daily life, which might in turn contribute to their picture comprehension abilities. For example, individuals with highly coordinated fine motor skills may spend extensive periods of time interacting with pictures via touch-screen devices, such as mobile phones and tablet computers, which they may even utilise as augmentative and alternative communication systems (Light & McNaughton, 2012, 2013). However, this theoretical explanation is speculative and warrants further investigation.

Participants achieved near ceiling-level accuracy in the picture comprehension task, but not the picture production task. This discrepancy in children's within-domain abilities aligns with previous findings demonstrating the superiority of neurotypical children's receptive skills relative to their productive skills across communicative domains (Callaghan, 1999; Carter & Hartley, in prep a, see Chapter 2). Children's picture production was significantly more accurate in modelled trials, and greater accuracy was associated with more developed fine motor skills. As in Hartley et al. (2019), language did not contribute to children's picture production abilities. Despite reporting that children's language and pictorial skills are positively related in neurotypical development, Kirkham et al. (2013) did not investigate trial type or include a measure of fine motor skills. This raises the possibility that language and pictorial skills were not associated in our study because greater proportions of variability in final models were captured by other variables that are potentially more relevant to graphic representation. The influence of fine motor skills in our study is unsurprising, considering the physical competence required to effectively use drawing implements to produce recognisable, representational drawings. Superior performance in modelled trials, where explicit demonstrations were provided by a more competent drawing partner, suggests that children's picture production abilities are scaffolded by the provision of exemplar models during social interactions with symbolically competent adults (Callaghan et al., 2011, 2012). Relatively poor performance on unmodelled trials could be associated with differences in generativity and planning in ASD, which may have impacted participants' ability to imagine how an unfamiliar 3D object could be translated into 2D markings (Low et al., 2009).

In the Birthday Party task, better performance on trials that involved singing “Happy Birthday”, putting candles on a cake, and giving a baby doll a drink, were predicted by higher CARS scores. Although this effect is somewhat surprising, it is possible that children with more severe autism were more inclined to join in with these sensory, play-based tasks involving music, playdough, and dolls because these kinds of activities are more suited to their developmental level and closely mirror the types of adaptations implemented at school to increase participation and engagement (Milbourne & Campbell, 2007; Sandall & Schwartz, 2008). Children’s responding on trials that involved blowing out candles, feeding a baby doll, cleaning up a spillage and putting a baby doll to sleep were predicted by more developed fine motor skills. This association could be attributed to the fact that these tasks involved children manipulating objects with their fingers and hands, which requires co-ordination of muscles and joints, as well as visual and haptic perception (Case-Smith & Exner, 2015). During independent free play, younger children were more likely to require adult intervention and exhibit unusual sensory interests, compared to older children. This effect of age could reflect increased experience engaging in symbolic play, and possibly be attributed to a reduction of unusual sensory interests with developmental maturation (Murphy et al., 2005).

Language did not appear to mediate children’s symbolic play skills in our study, which contradicts previous research evidencing a relationship between receptive and expressive linguistic difficulties and play in ASD (Sigman & Ruskin, 1999; Sigman & Ungerer, 1984; Warreyn et al., 2005; Whyte & Owens, 1989). However, according to Stanley and Konstantareas (2007), only language production is related to symbolic play. While language comprehension involves processing verbal input, both symbolic play and language production require children to generate actions and words independently, indicating that symbolic play may be more strongly related to the generative rather than the interpretative function of language (Jarrold et al., 1993). Therefore, the lack of a relationship between language and play in our study could be attributed to the fact there was no direct requirement for our participants to talk during independent free play, and on only one occasion during the Birthday Party task (i.e. singing Happy Birthday).

Children's responding on social communication trials was related to their expressive language abilities and chronological age. RJA was associated with higher expressive language scores, which aligns with previous research demonstrating a predictive relationship between joint attention and language production in ASD (Blume et al., 2020; Siller & Sigman, 2008). In contrast, children's responsiveness to their name was predicted by lower expressive language scores. This could reflect an increased propensity for adults to overtly secure the attention of the minimally verbal children they support, by using orienting cues (e.g. calling their name) prior to shifting attentional focus (Walton & Ingersoll, 2015). Intentional and consistent use of this specific strategy by a more competent social partner might serve as an important cue to mediate children's responsiveness to attention-directing bids, especially as autistic individuals are less likely to spontaneously monitor their partner's attention and notice attentional shifts (Goldstein et al., 2007; Presmanes et al., 2007). As IJA was not predicted by language in our study, this provides support for the notion that different types of joint attention may follow distinct developmental trajectories and uniquely contribute to language development (Adamson et al., 2009; Mundy & Jarrold, 2010).

Children's use of eye contact and social smiling were related to age, although these effects were in different directions. Younger children were more likely to make appropriate eye contact with the examiner, compared to older children, which could be driven by increased engagement during interactive, adult-initiated play tasks involving motivating toys and objects (Nadig et al., 2010; Jones et al., 2018). Older children were more likely to smile in response to the purely social overture initiated by the examiner, compared to younger children. This could reflect increased experience engaging in social interactions with others, and possibly be attributed to improved social inferencing skills with developmental maturation (Saldaña & Frith, 2007).

The predictive influence of fine motor skills identified across play and pictorial domains could be evidence for embodied cognition contributing to autistic children's symbolic development. Theories of embodied cognition emphasise the interplay between the mind *and* the body in constructing mental processes; as we interact with the world, our perceptual and motor experiences influence our cognitive development (Wellsby & Pexman, 2014; Wilson, 2002). As autistic individuals pursue and act on physical rather than interpersonal stimuli, perceiving social stimuli as less salient, their experience of the world may be "socially disembodied" (Dawson et al., 1998; Klin et al., 2003; Gale et al., 2019). So, despite the inherently social context of our play and pictorial tasks, our participants may have been more attuned to the toys, experimental objects, and pictures, resulting in physically encoded experiences, which in turn could mediate their ability to infer symbolic understanding and acquire productive actions (e.g. drawing and symbolic play).

In our study, more developed symbolic play skills and picture production abilities predicted greater picture comprehension accuracy. These findings are in alignment with previous research identifying associations between symbolic play and graphic symbolism in neurotypical development (Kirkham et al., 2013; Carter & Hartley, in prep a, see Chapter 2). When considering the interrelations evidenced in our data, it is important to acknowledge that both symbolic play and pictorial understanding require representational insight – the basic realisation of the symbolic relationship between a symbol and its referent (DeLoache, 1995). To understand pictures as symbols, children must recognise that the 2-D graphic markings on a page represent an independent 3-D referent (DeLoache, 1995; Sigel, 1978), and during complex symbolic play, children are required to act as if inanimate objects have agency, or pretend they are something else entirely (Lewis et al., 1992). Thus, representational insight is implicated as a potential common mechanism underlying both non-linguistic symbolic domains in autistic development (Pleyer, 2020).

Our findings demonstrate that more sophisticated symbolic play was predicted by variability in pictorial abilities and social communication skills. While development and sophistication in non-linguistic symbolic domains appears to be acquired through social-cognitive engagement with others (i.e. during the symbolic play tasks, and the drawing task where children performed more accurately with scaffolding), proficiency in play and pictorial domains do not appear to contribute to social communication abilities. This lack of a bidirectional relationship contrasts with findings on neurotypical development (Carter & Hartley, in prep a, see Chapter 2). Although more socially oriented autistic individuals may spend more time engaging in pictures and play with others, it is possible that they only develop proficiency with the non-linguistic symbol systems, instead of also advancing socially. This could be because autistic children perceive social stimuli as less salient than physical stimuli, and selectively attend to the latter, which results in “developed specialisation of things rather than people” (Klin et al., 2003, p. 357).

Our findings provide the most comprehensive account of concurrent relationships between symbolic abilities and individual differences in ASD to date. The inter-domain relationships identified in this study could be exploited by clinical and educational interventions aimed to facilitate symbolic development in ASD. Considering that certain tasks may have cross-domain benefits, as opposed to simply benefitting a single targeted domain, it is possible that children who demonstrate difficulties in one symbolic domain (e.g. pictorial understanding) may benefit from play-based interventions that specifically target their receptive and expressive abilities in other related symbolic domains (i.e. social communication and play). Indeed, a play-based intervention for autistic individuals that teaches social-communication skills mediated children's initiation of and response to joint attention, symbolic play skills, and predicted more developed expressive language skills one year post-intervention (Kasari et al., 2006, 2008).

Our study has several limitations that require acknowledgement. Firstly, although our data indicate how variables concurrently interrelate at time of testing, we are unable to draw any causal, developmental conclusions. Furthermore, it is not possible to comment on the specific ages at which these relationships change, because we did not examine discrete age groups. Therefore, we recommend that future studies employ longitudinal designs to establish causal relationships between children's early acquisition and subsequent development of symbol systems, and identify developmental interrelationships between domains (e.g. Kirkham et al., 2013). Examining relationships between symbolic domains has important implications for understanding both neurotypical and neurodiverse development (Karmiloff-Smith, 2009; D'Souza & Karmiloff-Smith, 2011), so future research should compare matched samples of neurotypical children and autistic children. This would inform our understanding of whether the direction and magnitude of predictive relationships between symbolic domains differs between these populations. Secondly, as we did not record details regarding participants' exposure to interventions, it is difficult to determine the influence of such extraneous variables. Finally, given the heterogeneity of ASD, our findings may only reflect certain demographic characteristics (e.g. delayed language development). This limits the generalisability of our results across the autism spectrum and could be remedied by recruiting larger and more diverse samples in future studies.

In summary, the present study revealed concurrent interrelationships between play and pictorial domains, indicating that these modules of symbolic development may be underpinned by shared cognitive mechanisms in ASD. While social interactions with more symbolically experienced partners appear to provide important scaffolding opportunities for developing receptive and expressive play and pictorial abilities, it seems that clinical differences in social ability inhibits autistic children from making reciprocal improvements in social communication. Overall, these findings are consistent with Vygotskian social-cultural theories, suggesting that autistic children's social communication skills provide a scaffolding base for other symbolic domains. From a practical perspective, our findings could help to inform the design and delivery of clinical and educational interventions targeting symbolic development in ASD.

Chapter 4: Do concurrent relationships between language and non-linguistic symbolic domains differ between autistic and neurotypical development?

Chapter Introduction

Recent research has examined concurrent interrelations between symbolic and social-cognitive domains in neurotypical and autistic children independently, identifying associations which suggest that symbolic understanding may differ between these populations (Carter & Hartley, in prep a; Carter & Hartley, in prep b). However, additional research is required to determine if these findings persist when directly comparing language-matched samples from both groups. Therefore, this chapter presents a study that explores potential variations in predictive relationships between symbolic domains and demographic characteristics in autistic and neurotypical children, specifically matched on receptive language abilities. The results of this investigation will advance theoretical understanding by elucidating whether and how relationships between pictorial understanding, symbolic play, and social communication differ between neurotypical and autistic children when expectations are based on their language abilities.

Author Contribution: *Cheriece Carter*: design, data collection, analysis, writing, review. *Calum Hartley*: design, analysis, review.

Abstract

Learning to use and understand culture-specific symbol systems (i.e. gestures, pictures, and words) can be particularly challenging for autistic children who commonly experience language delays and differences in social communication. In neurotypical development, social communication skills are intimately related to language acquisition, which in turn may scaffold the development of other non-linguistic symbol systems. Delays and differences in these scaffolding bases could result in critical downstream consequences for symbolic understanding in autism. For the first time, the present study examined whether predictive relationships between social, pictorial, and play domains differ between autistic and neurotypical children matched on language comprehension (*M* age equivalent = ~ 44 months). Participants completed a battery of standardised assessments and experimental tasks, to capture children's raw performance in the domains of pictures, play, and social communication, and ascertain whether relationships differ across populations. While concurrent multidirectional relationships between play, pictures, and social communication were identified in neurotypical children, this was not observed in autism. Thus, our findings suggest that neurotypical children's understanding of non-linguistic symbols are interdependent and mediated by social-cognitive abilities, whereas in autism, symbolic domains may be relatively more independent.

Introduction

To communicate effectively and fully participate in society, children must learn to use and understand a wide range of culture-specific symbol systems, including gestures, pictures, and words (Callaghan et al., 2011; DeLoache, 2004; Klin et al., 2002). Acquiring these important cultural conventions from others can be challenging for autistic children, who commonly experience language delays (Anderson et al. 2007; Howlin et al. 2009) and exhibit differences in social-motivation and social-cognition (Carpenter et al., 2001; Chevallier et al., 2012; DSM-V; American Psychiatric Association, 2013). As language may provide a vital scaffold for the acquisition of other symbol systems in early neurotypical (NT) development (Kirkham et al., 2013; Vygotsky, 1978), early difficulties in this foundational domain may have critical downstream consequences for other communicative domains, including pictures and play. Carter and Hartley (in prep a, in prep b) recently examined concurrent interrelations between symbolic and social-cognitive domains in neurotypical 2–5-year-olds (see Chapter 2) and autistic 4–11-year-olds (see Chapter 3), and identified associations which suggest that symbolic understanding in autism spectrum disorder (ASD) may be underpinned by qualitatively different learning mechanisms. However, further research is required to elucidate whether these findings remain when comparing language-matched samples drawn from both populations. Therefore, this study will examine whether predictive relationships between symbolic domains and demographic characteristics differ between autistic and neurotypical children.

Throughout the literature, there are numerous theoretical models of symbolic development that predict different hypotheses concerning interrelations between communicative domains in neurotypical children. Firstly, domain-specific accounts envisage that the mind is composed of separate modules, and each module 'should do one thing well' (Pinker, 1997, p. 91). As language is viewed as distinct from other cognitive systems

(Chomsky, 1957), and each module is functionally dedicated to solving specific problems in separate domains, this account would argue that language, symbolic play, and pictures develop independently, thus predicting no concurrent or longitudinal relationships between the three symbolic domains. Conversely, domain-general approaches posit that generalised cognitive mechanisms support learning across different domains in relative synchrony (Piaget, 1952). According to this view, language is contingent upon specific cognitive prerequisites (e.g. understanding categorisation; Gopnik & Meltzoff, 1992). The fundamental achievement of abstract thought (e.g. representational insight; DeLoache, 2000) is regarded as a shared internal process that establishes important foundations for enabling expression of meaning across all symbolic systems, alongside other important required skills, including vocal/motor control and visual memory (McCune, 2008). Consequently, domain-general accounts predict positive concurrent relationships between language, symbolic play, and pictures. Finally, socio-cultural theories inspired by Vygotsky (1962, 1978) strongly emphasise the importance of language, arguing that it emerges prior to, and mediates subsequent development of, other symbolic domains. Language acquisition is considered to emerge from episodes of joint attention with other more experienced symbol users. During these social interactions, infants hone their attentional behaviours (progressing from simple gaze following, to imitation, and pointing) and gradually develop their understanding of others as intentional agents (Tomasello et al., 1993). These achievements facilitate the process of abstract mental representation by enabling infants to consider, and reflect on, multiple perspectives (Tomasello, 1999). Thus, constructivists would argue that language, symbolic play, and pictures develop in a fixed sequence, with language emerging first – as a scaffolding base – and predicting other abilities over time.

In neurotypical development, infants rapidly develop a repertoire of social-cognitive skills that allow them to adopt crucial symbol systems between birth and 4 years (Callaghan et al. 2011). For example, language – the most privileged symbol system – reliably emerges after a range of attention monitoring behaviours that develop between 9–12 months and is predicted by time spent in infant-mother engagement (Carpenter et al., 1998; Tomasello, 2003b). Language, in turn, has been shown to predict other non-linguistic symbolic domains, including pictures and play (Kirkham et al. 2013; Vygotsky, 1978). Two longitudinal studies have examined interrelationships between multiple symbolic domains in neurotypical development. Callaghan and Rankin (2002) assessed the receptive and expressive abilities of 2–3-year-olds in language, symbolic play, and graphic symbolism, and identified significant positive correlations between: i) comprehension of language and pictures, ii) production of language and pictures, and iii) comprehension of play and pictures. Subsequently, in Kirkham et al. (2013), relationships between these three symbolic domains were examined in a larger sample of neurotypical 3–5-year-olds. They found that language *predicted*, but was not *predicted by*, graphic symbolism. Relationships between symbolic play and graphic symbolism approached statistical significance. While the predictive relationships identified by Callaghan and Rankin (2002) align more closely with Piagetian domain-general perspectives of symbolic development, Kirkham et al.'s findings are more consistent with Vygotskian social-cultural accounts of symbolic understanding.

In a more recent study, Carter and Hartley (in prep a, see Chapter 2) investigated concurrent inter-domain relationships in neurotypical 2–5-year-olds across social communication, language, play, and pictures. They found that more advanced symbolic play was associated with more sophisticated language skills, more accurate picture production was associated with more developed fine motor skills and observing adult modelling, and superior symbolic play and picture comprehension were predicted by higher non-verbal intelligence. These findings indicate that performance across symbolic domains is predicted by myriad cognitive individual differences. In contrast with previous research (Callaghan & Rankin, 2002; Kirkham et al., 2013), language did not contribute to children's use and understanding of pictures or social communication, although there was evidence of a scaffolding role of language for play, potentially indicating that other variables may have greater influences on graphic representation and social communication as children get older and their skills in these domains improve. Furthermore, they found a strong positive relationship between picture production and symbolic play, symbolic play skills were associated with social communication and picture comprehension abilities, and social communication skills were predicted by variability in picture production and symbolic play. These concurrent interrelationships between multiple domains indicate that these modules of symbolic development may be underpinned by shared factors, thus providing support for domain-general perspectives.

Diagnosis-defining differences in social-motivation and social-cognition in ASD can inhibit children's ability to acquire language from others (Carpenter et al., 2001; Chevallier et al., 2012). While most autistic individuals eventually acquire functional spoken language (Lord et al., 2004), they generally achieve language milestones much later than neurotypical children (Howlin, 2003). On average, autistic children's first spoken words emerge at approximately 36-months-old (Anderson et al., 2007; Howlin et al., 2009), and between 12- and 18- months-old in neurotypical development (Tager-Flusberg et al., 2009; Zubrick et al., 2007). If language mediates the acquisition of other symbol systems in early neurotypical development (Kirkham et al., 2013; Vygotsky, 1978), early difficulties in this foundational domain could have critical downstream consequences. Indeed, empirical research indicates that minimally verbal autistic children also have difficulty understanding pictures (Hartley & Allen, 2015a) and symbolic play (Stanley & Konstantareas, 2007), suggesting differences in development of these domains. This theory is strengthened by the fact that autistic children do not show the normative advantage for receptive over expressive communication skills

(Hudry et al., 2014).

There is a paucity of research investigating inter-domain relationships across multiple symbolic domains in ASD, while accounting for important individual differences (although see Stanley & Konstantareas, 2007). Carter and Hartley (in prep b, see Chapter 3) addressed this critical gap in the literature by examining how variability in language, and other individual differences, predicted the abilities of 4–11-year-old autistic children in the domains of pictures, play, and social communication, as well as modelling concurrent relationships between the non-linguistic symbolic domains. They found that more accurate picture comprehension and production were associated with more developed fine motor skills, and trials where linguistic scaffolding or adult modelling were available. Also, more advanced symbolic play was associated with older age and more developed fine motor skills. Furthermore, social communication skills were predicted by variability in age and expressive language ability. These findings indicate that symbolic domains are predicted by cognitive individual differences, some of which influence multiple domains (i.e. fine motor skills), and interactions with more symbolically experienced partners may scaffold picture comprehension and production skills in ASD. Furthermore, they found superior pictorial comprehension was associated with more advanced symbolic play and picture production skills. In addition, more sophisticated symbolic play skills were predicted by variability in pictorial abilities and social communication skills. However, social communication abilities were not predicted by pictorial or play skills, which indicates that social-cognitive engagement with others facilitates participants' performance during the drawing and symbolic play tasks, but proficiency in these symbolic domains does not appear to contribute to social communication abilities. This contrasts with findings from neurotypical children (Carter & Hartley, in prep a, see Chapter 2), suggesting that social communicative skills may enable autistic children to acquire non-linguistic symbolic skills through interactions, but engaging in these activities might not reciprocally improve social skills.

If language mediates children's use and understanding of other communicative domains, then autistic children who have profoundly delayed language development are likely to exhibit delays and differences in pictorial and symbolic play abilities. Previous research examining picture comprehension abilities demonstrate differences in understanding of symbolic word-picture-object relationships in this population relative to language-matched neurotypical controls (Hartley & Allen, 2014a, 2014b, 2015a, 2015b; Preissler, 2008). Autistic children have difficulty discerning that information directed at pictures (e.g. linguistic labels) relates to symbolised referents, particularly when iconicity is low (Hartley & Allen, 2015a; Preissler, 2008), and tend to extend labels from pictures based on category-irrelevant features, such as colour (Hartley, 2014a). Furthermore, understanding of symbolic word-picture-object relations in ASD may not be informed by inferences about social-communicative intentions underlying pictures (Hartley & Allen, 2014b, 2015c).

When matched on language ability or mental age, autistic children demonstrate comparable picture-object matching and picture production abilities to neurotypical controls (Hartley et al., 2019; Jolley et al., 2013; McCarthy et al., 2018). For example, in a picture-object matching task which manipulated the availability of linguistic scaffolding, autistic children and neurotypical controls matched on both receptive and expressive language performed more accurately during trials which afforded verbal mediation, compared to trials which did not (Hartley et al., 2019). This suggests that successful deciphering of picture-referent relations was facilitated by verbal scaffolding in ASD and neurotypical development. In an object-drawing task which manipulated availability of adult modelling, both groups were more accurate in modelled trials relative to unmodelled trials (Hartley et al., 2019). These findings suggest that autistic children's picture production skills are unimpaired when expectations are based on their linguistic abilities, indicating a potential relationship between these two domains. If language mediates children's ability to produce representational drawings, then early difficulties in the pictorial domain may diminish as their expressive language skills develop. During picture production tasks that require participants to depict 'impossible' entities, autistic children's drawing performance is equivalent to neurotypical children and children with learning difficulties, when provided with pre-drawn templates to complete (e.g. a headless dog; Allen, 2009). Given that mental age and imaginative drawing abilities were related in ASD, but not in children with learning difficulties, Allen (2009) proposed that language comprehension may mediate imaginative drawing processes in this population. If this is the case, individuals with more severe language difficulties may also have difficulties learning to draw. Thus, by extension, we would not expect to find any differences between autistic and neurotypical children when matched on language.

Autistic children are less responsive to social bids for attention initiated by others (via pointing, verbal language, and gaze shifting) in comparison to neurotypical controls (Chawarska et al., 2012), and rarely attempt to initiate joint attention with others through declarative pointing (Mitchell et al., 2006; Swinkels et al., 2006). During interactions with others, pre-school aged autistic children spend more time attending to objects, and less time engaged with partners, relative to age-matched neurotypical controls (Adamson & Chance, 1998; Dawson et al., 2004; Swettenham et al., 1998; Werner & Dawson, 2005). Thus, from a very young age, autistic individuals may have reduced exposure to people and the important social information provided by facial, gestural and gaze cues, which could result in this population being less experienced and less 'expert' in social interactions compared to neurotypical children (Charman, 2003). While it is well documented that joint attention lays crucial foundations for the development of language (Carpenter et al., 1998; Morales et al., 1998, 2000; Mundy & Gomes, 1998), some researchers argue that it could also facilitate the acquisition of other symbolic domains, such as pretend play in both typical development

(Carpenter et al., 1998; Meltzoff, 2005) and in ASD (Charman, 2003; Sigman & Capps, 1997).

Pretend play skills appear to be strongly related to language, and social-cognitive abilities, in both neurotypical development (Lillard et al., 2013; Orr & Geva, 2015; Quinn et al., 2018; Smith & Jones, 2011; Zlatev & McCune, 2014) and ASD (Binns et al. 2022; Kasari et al., 2008; Stanley & Konstantareas, 2007; Thiemann-Bourque et al., 2012; Toth et al, 2006; Warreyn et al., 2005; Yoder et al., 2015). However, very few studies present evidence for predictive relationships (Russ & Wallace, 2013), and many focus on analysing specific domains in isolation, which makes it difficult to disentangle these close correlations. Although the nature of the play-language relationship is unclear, and requires further investigation, it could be driven by the language and social scaffolding provided by more symbolically competent adults during play episodes (Jarrold, 2003; Lewis, 2003; Lillard et al., 2010), or outside of play when children talk about pretence with others (Bergen, 2002). Although delays and differences in play skills are commonly observed in ASD – with play episodes featuring fewer instances of spontaneous pretend play, and more instances of functional and/or restricted, repetitive play acts compared to neurotypical children (Hobson et al. 2015; Jarrold, 2003; Moerman et al., 2023; Thiemann-Bourque et al., 2019; Wetherby et al., 2004) – more developmentally complex symbolic play activities can be elicited if autistic children receive verbal prompts and demonstrations of play acts (Blanc et al., 2005; Rutherford et al., 2007). In our language-matched samples of autistic and neurotypical children, we are likely to find more severe social-cognitive difficulties in the autistic group. Thus, we may detect differences in the predictive relationships between social communication and play across populations. For example, in ASD, play abilities may develop independently and be unrelated to social-cognitive abilities (Mundy, 1995), in contrast to neurotypical development where domains are more interdependent and social communication mediates symbolic understanding of play (Anderson et al., 2007).

The objective of the present study was to investigate whether raw performance of language-matched samples of autistic and neurotypical children differs in the domains of pictures, play, and social communication, and determine whether relationships between domains differ in terms of their presence, direction, and magnitude across populations. This study follows the same procedure used in Carter and Hartley (in prep a, in prep b; see Chapters 2 and 3). As existing research predominantly fails to acknowledge that young children's comprehension skills outweigh their productive skills in every symbolic domain (Callaghan, 1999), it is essential that both receptive *and* expressive abilities in each domain are measured to comprehensively profile children's symbolic abilities. Picture comprehension was assessed via a picture-object matching task based on Callaghan (2000), which manipulated whether children could utilise verbal labelling to scaffold their performance. Picture production was tested using an object-drawing task based on Kirkham et al. (2013), which required children to draw pictures of unfamiliar target objects with, and without, adult modelling. Symbolic play was assessed via a series of tasks adapted from the Autism Diagnostic Observation Schedule Version 2 (ADOS-2; Lord et al., 2012), which were designed to elicit children's spontaneous, independent play abilities during a free play session, as well as functional and symbolic play skills during the context of a familiar social routine led by an adult (i.e. a birthday party). Measures of social communication (e.g. initiation of joint attention and response to joint attention; use of eye contact; social smiling; and spontaneous giving of items to others) were also tested using several tasks derived from the ADOS-2 (Lord et al., 2012).

Based on previous evidence (e.g. Callaghan & Rankin, 2002; Carter & Hartley, in prep a, in prep b; Hartley et al., 2019; Kirkham et al., 2013), we expected to identify differences between neurotypical and autistic children in the direction and magnitude of predictive relationships between symbolic domains (due to delays and difficulties; Mundy, 1995). While social-cognitive engagement with more symbolically experienced social partners may strongly mediate symbolic abilities across all domains in neurotypical development, diagnosis-defining differences in social-motivation and social-cognition in autism may relatively reduce these facilitative effects. Symbolic domains may be concurrently interdependent in neurotypical children, thus providing support for domain-general accounts of symbolic development (Callaghan & Rankin, 2002; Carter & Hartley, in prep a, see Chapter 2; Piaget, 1952). Although recent evidence identifies predictive relationships in autism that align with social-cultural perspectives (Carter & Hartley, in prep b, see Chapter 3), the strength of associations may be weaker than in NT development, indicating relative independence of domains (Chomsky, 1957; Pinker, 1997**)**. The findings of our study will provide the most detailed account of concurrent relationships between symbolic abilities and individual differences in neurotypical and autistic development to date, and potentially reveal inter-domain relationships that can be exploited by interventions in clinical and educational contexts.

Method

Participants

Participants were 27 autistic children (18 males, 9 females; *M* age = 87.07 months, *SD* = 27.79) recruited from specialist schools, and 27 neurotypical children (15 males, 12 females; *M* age = 43.04 months, *SD* = 6.85) recruited from mainstream nurseries (see Table 1). All children had normal or corrected-to-normal vision. Groups were matched on their receptive language skills, as measured by the Receptive Language module of the Mullen Scales of Early Learning (Mullen, 1995). Autistic children had a mean language comprehension age of 44.11 months (*SD* = 14.59) and neurotypical children had a mean language comprehension age of 44.30 months (*SD* = 10.49), $t(52) = 0.05$, $p = .96$. Expressive language abilities were measured using the Expressive Language module of the Mullen Scales of Early Learning (Mullen, 1995). Autistic children had significantly lower expressive age equivalents than neurotypical children (ASD: M = 37.78 months; SD = 19.08; NT: M = 46.44 months; SD = 11.97), $t(52) = 2.00$, $p = .05$. Fine motor abilities were measured using the Fine Motor module of the Mullen Scales of Early Learning (Mullen, 1995). The groups' fine motor skills did not significantly differ (ASD: M score: 44.78, SD = 11.86; NT: M score: 47.19, SD = 10.60), $t(52) = 0.79$, $p = .44$.

Autistic children were previously diagnosed by a qualified educational or clinical psychologist, using standardised instruments (i.e. Autism Diagnostic Observation Schedule Version 2; Lord et al., 2012 and Autism Diagnostic Interview-Revised; Lord et al., 1994) and expert judgment. Diagnoses were confirmed via the Childhood Autism Rating Scale Second Edition (CARS-2; Schopler et al., 2010), which was completed by each participant's class teacher (ASD: M score: 37.46, SD = 5.21; NT: M score: 16.69, SD = 2.37).

Autistic children were significantly older ($t(52) = 7.99$, $p < .001$, $d = 2.18$), and had significantly higher CARS scores ($t(52) = 18.87$, $p < .001$, $d = 5.13$) than neurotypical children. Children's non-verbal intellectual abilities were measured using the Leiter-3 (Roid et al., 2013). The mean (age-normed) IQ for the ASD group was 76.93 (SD = 13.68; range 41–107) and the mean IQ of the neurotypical group was significantly higher at 100.60 (SD = 5.67; range 90–113), $t(50) = 8.03$, $p < .001$. The groups' raw scores on the Leiter-3 were also significantly different (ASD: M score: 55.44, SD = 12.63; NT: M score: 47.00, SD = 6.15), $t(52) = 3.12$, $p = .003$. While higher raw scores in the ASD group indicate marginally more advanced non-verbal abilities at time of testing compared to the neurotypical group, autistic children's progress was not commensurate with their age, hence their lower IQ scores. All procedures performed in this study were in accordance with the ethical standards of institutional and national research committees. Informed consent was obtained from caregivers prior to their children's involvement in the research.

Table 1

Sample characteristics (standard deviation and range in parentheses)

Population	*N*	Gender	Chron. age [months]	Mullen receptive language age equiv. [months]	Mullen expressive language age equiv. [months]	Mullen fine motor age equiv. [months]	CARS-2 score	Leiter-3 IQ score	Leiter-3 raw score
NT	27	15 males, 12 females	43.04 (6.85; 29–53)	44.30 (10.49; 28–62)	46.44 (11.97; 26–70)	47.19 (10.60; 24–65)	16.69 (2.37; 15–24)	100.60 (5.67; 90–113)	47.00 (6.15; 32–61)
ASD	27	18 males, 9 females	87.07 (27.79; 48–137)	44.11 (14.59; 22–69)	37.78 (19.08; 3–70)	44.78 (11.85; 28–68)	37.46 (5.21; 30–49)	76.93 (13.68; 41–107)	55.44 (12.63; 36–79)

Note. NT: neurotypical; ASD: autism spectrum disorder; CARS-2: Childhood Autism Rating Scale Version 2

Materials

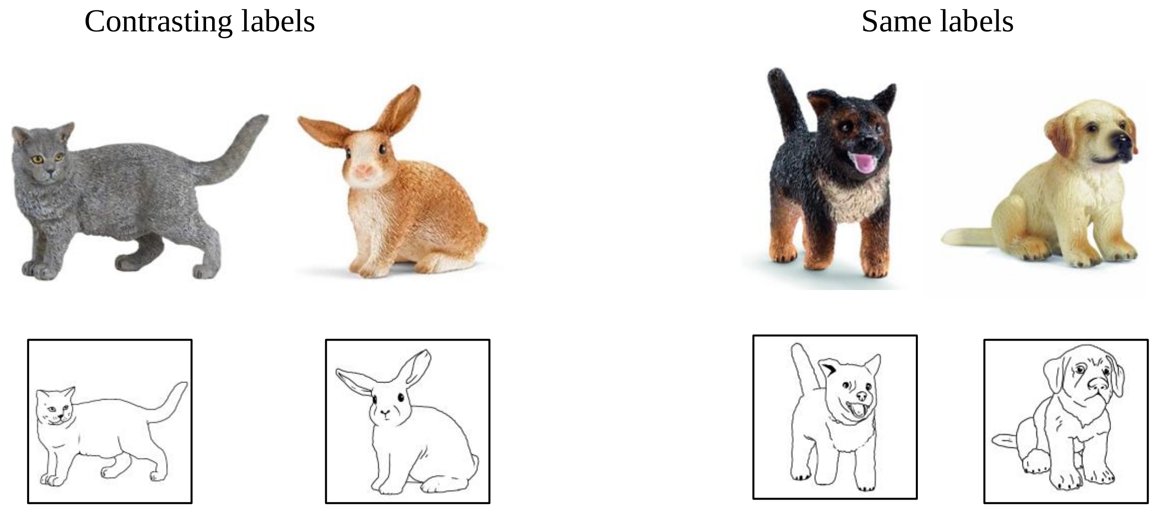
Stimuli and tasks were identical to those described in Carter & Hartley (in prep b, see Chapter 3).

Picture Comprehension

Stimuli included 16 objects and 16 black-and-white line drawings of those objects. All objects were highly familiar and were selected on the basis that most children understand their linguistic labels by 16 months (Fenson et al., 1994). These objects included: cat, bunny, bicycle, motorbike, hairbrush, comb, plastic carrot, plastic banana, two cars, two dogs, two spoons, and two shells. Perceptual similarity of object pairs was controlled for across trial types. For example, in "contrasting labels" trials (i.e. where choice objects belonged to distinct linguistic categories) a standing cat and a sitting bunny were paired together. In "same labels" trials (i.e. where choice objects belonged to the same linguistic categories) a standing dog and a sitting dog were paired together. All pictures used in this study were laminated and measured 5 cm x 5 cm, which is the recommended sizing for Picture Exchange Communication System symbols (PECS; Frost & Bondy, 2002). Examples of paired object stimuli and black-and-white line drawings are displayed in Figure 1. All line drawings had a broadly similar level of detail to ensure that they did not differ markedly in terms of iconicity.

Figure 1

Examples of object stimuli pairs and line drawings used in the picture comprehension task



Picture Production

Stimuli included six different unfamiliar objects, which were divided into two sets (see Figure 2), pencils, and white A5 paper sheets. The novelty of the items ensured that children's responses could not be facilitated by pre-practised drawing routines associated with familiar concepts.

Figure 2

Objects used in the picture production task

Symbolic Play

In the Free Play task, stimuli included a selection of toys: multiple pop-up toy, nesting cups, two animal figures, board book, toy telephone, four pieces of yarn, gold lid, baby doll with open/shut eyes, eight letter blocks, two identical balls, two identical cars, two pairs of plastic utensils, and four plastic plates. Response to Joint Attention was tested using a remote-controlled bunny. In the Birthday Party task, stimuli included a baby doll with open/shut eyes, a plastic plate, a plastic fork, a plastic knife, a plastic cup, a napkin, a jar of play dough, four glue-gun refill 'candles', and a small blanket.

Procedure

Participants were tested individually in their own educational settings, accompanied by a familiar adult when required (e.g. key worker, teacher, or teaching assistant). Children were verbally praised for attention and good behaviour while completing the standardised and experimental assessments, which took the form of fun, short "games" administered in separate sessions, on different days. Order of tasks was randomised for each participant.

Language

The Mullen Scales of Early Learning (MSEL; Mullen, 1995) were used to assess

children's language comprehension and language production, as it benefits from very low language demands (it is suitable for children aged < 1 year) and is frequently administered to autistic children.

The Receptive Language module provided a measure of children's language comprehension. Children completed tasks which involved auditory discrimination and auditory/motor integration e.g. recognition of familiar names and words, identification of objects and pictures, performing simple actions on request, comprehending questions, testing spatial concepts, and identification of colours and numbers. The Expressive Language module provided a measure of children's language production. Tasks related to overall productive verbal abilities e.g. producing letter sounds, combining words and gestures, naming simple objects, labelling pictures, use of two-word phrases, use of pronouns, counting, use of short sentences, repetition of word sequences, and verbal analogies. Raw scores for both modules were converted into age equivalents based on the normed guidelines in the assessment handbook.

Non-verbal Intelligence

The Leiter International Performance Scale Third Edition (Leiter-3; Roid et al., 2013) was used to test children's non-verbal intelligence and provide a measure of IQ. The Leiter-3 was chosen as it can be administered non-verbally and children's responses can be entirely non-verbal. The Brief Assessment comprises four sub-tests of visualisation and reasoning that, together, provide a reliable measure of the respondent's IQ. These sub-tests assess children's ability to match colours, pictures, and shapes, identify specific features of pictures, mentally rotate images, and to infer/complete patterns. Participants' raw scores (possible range: 0–152) and IQ scores (possible range 0–170) were calculated as per the guidelines in the assessment handbook.

Fine Motor Skills

The Fine Motor module of the MSEL (Mullen, 1995) was administered to provide a measure of children's fine motor skills. Children completed tasks which involved motor planning and motor control. Some activities required bilateral manipulation (e.g. unscrewing/screwing a nut and bolt, threading beads, folding, and cutting) and others involved unilateral manipulation (e.g. stacking blocks, inserting pennies in slots, and drawing/writing). Raw scores were converted into age equivalents based on the normed guidelines in the assessment handbook.

Symbolic Play

Tasks derived from the Autism Diagnostic Observation Schedule Version 2 (ADOS-2; Lord et al., 2012) provided a measure of children's symbolic play. The ADOS-2 is a semi-structured, standardised assessment of communication, social interaction, play, and restricted and repetitive behaviours. The following tasks were administered by a trained experimenter, as per the guidelines in the Module 1 manual: Free Play and Birthday Party. An adapted scoring system was created to allow for in vivo scoring (see Appendix A).

Free Play. This task provided an opportunity for children to independently interact with a selection of toys arranged on a table in front of them. Initially, the experimenter directed the child's attention to the various toys ("Look at these toys. You can play with them.") Children were allowed to play without interruption for 3 minutes. If the child did not engage in any play during this time, or played exclusively with one toy in a limited and/or repetitive manner, the experimenter re-directed the child's attention to the various toys ("What can you do with these toys?"). If necessary, the experimenter also removed the main preoccupation. If the child had not exhibited any spontaneous pretend play after 3 minutes, the experimenter instructed the child to "Look…" and modelled simple pretend play (e.g. feeding the doll using a fork) for them to copy ("You do it."). Children were then allowed to play independently for a further 2–3 minutes.

During the Free Play task, the experimenter recorded which toys the child interacted with and categorised each interaction/play sequence using the following three categories: i) spontaneous pretend play, ii) functional play, iii) limited, repetitive play or no play. If a child demonstrated one or more instances of spontaneous pretend play (e.g. giving a doll a drink from a cup or pretending to talk on a toy telephone), they received two points. Instances of spontaneous pretend play which involved object substitution (i.e. using one object to stand for another) and/or attribution of agency (e.g. involving a figure or doll in an action) were noted. One or more observed instances of object substitution (e.g. pretending yarn is spaghetti) received an additional point. One or more observed instances of attributing agency (e.g. moving a figure or doll as if it is capable of action) scored an additional point. If a child did not demonstrate any instances of spontaneous pretend play, but exhibited functional play (e.g. stacking nesting cups or interacting with cause-and-effect toys), they achieved a total score of one. Limited, repetitive play (e.g. mouthing or banging objects) or no play attracted a score of zero. Total 'Free Play' scores could range from 0–4. The experimenter also noted whether adult intervention/modelling was required (0 = no modelling required; 1 = modelling required), and if so, whether the child imitated the modelled pretend play (0 = imitation; 1 = no imitation). If the child demonstrated an unusual sensory interest in play materials, such as flicking the doll's eyelids, this was also noted (0 = no observed instances of unusual sensory interest; 1 = one or more observed instances of unusual sensory interest).

Birthday Party. This task assessed children's functional and symbolic play skills in the context of a familiar social routine. The experimenter observed how children engaged with the doll/other materials, their degree of spontaneity, and evaluated whether the children understood the script of the party scenario. The task involved seven sequential stages:

Putting Candles on Cake. First, the experimenter directed the child's attention to the baby doll ("Look, here's Baby!) and explained, "It's Baby's birthday, let's have a birthday party." Next, the experimenter patted the play dough on a plate ("Here's the birthday cake…"), placed a 'candle' on the cake, handed one candle to the child and left the other two in reach ("Here are the candles."). If the child put the candles on the cake, they scored one point.

Singing Happy Birthday. The experimenter then 'lit' the candles with a pretend match, shook it out saying "Hot" and asked, "What should we do now?" If the child did not respond, the experimenter said, "Let's sing Happy Birthday!" and started to sing. If the child sang, they scored one point.

Blowing out Candles. If the child did not spontaneously blow out the candles or help the doll to do so, the experimenter prompted, "Let's blow out the candles!" and then asked, i) "What's next?" (ii) opened their mouth (iii) put mouth into a blowing position (iv) blew out the candles. The experimenter looked at the child with anticipation at each step. If the child helped the baby to blow out the candles using the doll as an independent agent, they achieved a score of three for this item. If the child blew out the candles, but did not use the doll as an independent agent, they scored two points. If the child imitated blowing out the candles after explicit demonstration, they scored one point. If the child did not blow out the candles, they received zero points.

Feeding Baby. The experimenter then gave the fork to the child and said "Baby's hungry." If the child fed the baby immediately, they scored three points. If the child fed the baby after a second prompt ("Baby wants birthday cake…"), they scored two points. If the child fed the baby after explicit demonstration, they scored one point. If the child did not feed the baby, they scored zero points.

Giving Baby a Drink. The experimenter prompted "Baby's thirsty." If the child used the nearby cup to give the baby a drink, they scored one point. If the child did not give the doll a drink, the experimenter pretended to pour some juice and give the doll a drink. If the child gave the baby a drink after this explicit demonstration, they scored one point. If the child did not give the baby a drink, they scored zero points.

Cleaning Up. The experimenter knocked over the cup, saying "Oh no, I spilled the drink! What should we do?" If the child immediately cleaned up (either using the nearby napkin, using another item as if it were a napkin or simply pretending to hold a napkin), they scored three points. If the child cleaned up after a second prompt ("Can you help clean up?"), they scored two points. If the child cleaned up after being handed the napkin, they scored one point. If the child still did not engage, the experimenter pretended to wipe up, and the child scored zero points for this item.

Putting Baby to Bed. The experimenter explained, "The birthday party has finished. Baby is tired. Can you help?" If the child immediately used the blanket (placed within reach on the table) to cover the baby, they achieved a score of three points. If the child used the blanket to cover the baby after the second prompt ("Baby is tired, time for bed…"), they scored two points. If the child covered the baby with the blanket, after being handed it, they scored one point. If the child did not cover the doll with the blanket, the experimenter performed the action and the child scored zero points for this item. Total scores for the Birthday Party task ranged from 0–15.

Videos from 10% of participants were independently coded by a second rater who was naïve to the participants' details and the study's hypotheses. Interrater reliability was calculated for each of the symbolic play tasks. There was complete agreement (k = 1.00, p = .008) on each individual aspect of the symbolic play tasks (i.e. Free Play and Birthday Party).

Social Communication

Measures of social communication were derived from activities included in the Autism Diagnostic Observation Schedule Version 2 (Lord et al., 2012). The following tasks were administered by a trained experimenter, during the Free Play session described above, as per the guidelines in the Module 1 manual: Response to Name, Response to Joint Attention and Responsive Social Smile. The experimenter also noted whether the child demonstrated unusual eye contact (0 = unusual; 1 = not unusual). During both the Free Play and Birthday tasks, the experimenter also noted whether the child spontaneously gave items to the experimenter (0 = no observed instances of giving; 1 = one or more observed instances of giving), or spontaneously initiated joint attention (2 = clear attempt to direct experimenter's attention towards a distal referent, and child looks back at the experimenter AND the referent; 1 = attempt to direct experimenter's attention towards a distal referent, but child does not look back at experimenter OR referent; 0 = no attempts to direct experimenter's attention towards a distal referent). An adapted scoring system was created to allow for in vivo scoring (see Appendix B).

Response to Name. This task probed whether the child responded to their name being called by the experimenter (or a familiar adult). While the child was engaged with a toy, or another activity of interest, and looking away, the experimenter moved behind and to the side of the child and called their name. If the child did not turn and make eye contact, the experimenter gave the child four more opportunities to respond. If the child looked at the experimenter and made eye contact after the first or second press, the child scored three points. If the child made an appropriate vocal response (e.g. "What?, "Huh?", "Yes?") but did not look, the experimenter re-administered this measure later. If the child looked towards the experimenter after the third or fourth press, they scored two points. If the child did not make eye contact, but shifted gaze briefly, or looked towards an interesting vocalisation, they scored one point.

Response to Joint Attention. This task examined whether the child responded to the experimenter's gaze shift/head movement to locate a target object that was concealed and out of reach. The experimenter initiated this activity when the child was already engrossed with another toy. Importantly, the experimenter never verbally referred to the toy at any point during this task.

First, the experimenter established the child's attention by calling, "[child's name], look!", then overtly shifted their gaze towards the referent (bunny), then back to the child. If the child followed the experimenter's gaze, the experimenter activated the toy and the child scored three points. If the child did not follow the experimenter's gaze, the experimenter called, "[child's name], look at THAT!", then overtly shifted their gaze towards the referent, then back to the child up to two times. If the child followed the experimenter's gaze on either press, the experimenter activated the toy and the child scored two points. If the child did not follow the experimenter's gaze, the experimenter called, "[child's name], look at THAT!", then pointed at the referent, overtly shifted their gaze towards the bunny, then back to the child up to two times. If the child followed the experimenter's point on either press, the experimenter activated the toy and the child scored one point. If the child did not follow the experimenter's point, the experimenter activated the toy for 5 seconds. If the child looked at the referent when activated, they scored one point, and the task ended. If the child did not look at the referent when activated, the experimenter activated the toy for a further 5 seconds. If the child still did not look at the referent, they scored zero points.

Responsive Social Smile. The objective of this task was to identify whether the child smiled in response to a purely social overture (laughter did not count). The experimenter initiated this activity when the child was not already smiling.

First, the experimenter established the child's attention by calling their name or using a toy, and said, "Look at you!" while smiling. If the child immediately smiled in response to the first or second smile, they scored three points. If the child partially smiled after the first or second smile, they scored two points. If the child did not respond, the experimenter allowed the child to continue with their activity for a moment, and then repeated the initial prompt. If the child smiled back after this additional press, they scored two points. If the child did not smile at the experimenter, the experimenter asked the teacher, “Can you show me how you get [child’s name] to smile without touching him/her?” If the child smiled at the familiar adult, the child scored two points, and the activity ended. If the child did not smile, the experimenter asked the familiar adult to touch the child to evoke a smile. If the child smiled in response to physical contact or repeated physical action, they achieved a score of one point. If the child never smiled in response to another person, they scored zero points for this item.

Videos from 10% of participants were independently coded by a second rater who was naïve to the participants’ details and the hypotheses in this study. Interrater reliability was calculated for each of the social-communication tasks. There was complete agreement on Response to Name (k = 1.00; p = .008), Response to Joint Attention (k = 1.00; p = .008), Responsive Social Smile (k = 1.00; p < .001), and Eye Contact (k = 1.00; p = .008). Interrater reliability was substantial for Giving (k = 0.70; p = .053) and Spontaneous Initiation of Joint Attention (k = 0.75; p = .013).

Picture Comprehension

A picture-object matching task (Callaghan, 2000) was used to assess children’s picture comprehension. Pictures and referent objects were used as stimuli in this task. Children were presented with a black-and-white line drawing of an object for 4s. The experimenter pointed to the depicted object and instructed the child to “look at this picture!” The drawing was then removed from view, and two choice objects were presented – a target and a foil – approximately 30cm apart and equidistant from the participant. The experimenter asked children to “find the one in the picture.”

There were two trial types: contrasting labels (CL) and same labels (SL). Children completed 16 trials in total (8 of each type). In CL trials, the choice objects were familiar and belonged to distinct linguistic categories (cat, bunny, bicycle, motorbike, hairbrush, comb, plastic carrot, plastic banana). Crucially, children's picture-object matching in CL trials could be scaffolded by verbally labelling the picture and matching to a referent object with the same label. In SL trials, the choice objects were familiar but belonged to the same linguistic categories (two cars, two dogs, two spoons, two shells). Although, the items in SL trials were familiar, children's picture-object matching could not be scaffolded by verbal labelling; both potential referents had the same label, and therefore could only be discriminated based on resemblance to the picture. Perceptual similarity of object pairs was controlled for across trial types. The order of trial types was randomised for each participant, subject to the criterion that no more than two trials of the same type (CL or SL) were presented consecutively.

In accordance with standard coding criteria (e.g. Allen et al., 2015; Hartley & Allen, 2015a; Preissler, 2008), only intentional responses were coded (e.g. giving or sliding an object to the experimenter, pointing to, or picking up and showing the experimenter an item). For example, if a child manually explored the foil object having already clearly indicated that the target was the depicted referent via pointing or vocalisation, their response was coded as correct. If children correctly identified the depicted target object, they scored one for that trial. If they incorrectly identified the foil, they scored zero. Total scores could range from 0–16 and performance on each trial type could range from 0–8.

Picture Production

An object-drawing task based on Kirkham et al. (2013) was used to assess children's picture production. Children were provided with a pencil and paper and instructed to draw six unfamiliar objects that were presented individually. Objects were selected on the basis that they could be drawn using circles and/or lines, as these tend to be the first drawing units that appear in children's early drawing attempts (Levin & Bus, 2003). Therefore, failure to produce an accurate representation of each object in the task should not be attributable to a motor production difficulty (Callaghan & Rankin, 2002).

For three objects, the experimenter modelled drawing a simple picture of the target object before the child created their drawing (Modelled Trials). The experimenter instructed participants to "watch carefully" while they were drawing and then highlighted the symbolic relationship between their drawing and the target object ("this drawing shows this object"). The experimenter's drawing was then removed before the child started drawing ("now, can you draw this object?"). These trials enabled us to assess children's picture production abilities when receiving explicit adult scaffolding. For the other three objects, the experimenter did not provide a demonstration before children created their drawings (Unmodelled Trials). This manipulation allowed us to gain a more precise account of children's picture production abilities under conditions that varied in difficulty. Participants were randomly assigned one of four different presentation orders that varied in terms of the objects allocated to Modelled and Unmodelled Trials and the order of trial types. No more than two trials of the same type were presented consecutively, and children were given up to 5 minutes to produce each drawing.

Every drawing was coded by the first experimenter and an independent rater with expertise in the field who was blind to the study's objectives, the participant's details (e.g. their age, diagnosis, etc), and whether the trial was Modelled or Unmodelled. The drawings were presented to the independent rater individually, and they were asked them to identify which of the 6 possible objects the child had depicted. If the rater matched the drawing to the correct referent object, children scored 1 (an incorrect match scored 0). Interrater reliability was very high ($k = .97$, $p < .001$).

At another time, as part of the overall battery of assessments, children also completed a Free Draw control task, to determine if they were capable of independently drawing representational pictures composed of circles and lines. Children were provided with a pencil and paper (for a maximum of 5 minutes) and instructed to "Draw a picture. You can draw anything you want to." Every drawing was coded by the first experimenter and an independent rater with expertise in the field who was naïve to the participants' details and the hypotheses in this study. Both raters were required to judge whether it was possible to: i) recognise what, if anything, was represented (0 = scribble/accidental markings; 1 = controlled, representational markings), ii) identify circles (0 = no circles; 1 = one or more circles), and iii) identify lines (0 = no lines; 1 = one or more lines). Interrater reliability was very high for both neurotypical (Representational: $k = 0.91$; $p < .001$; Circles: $k = 0.91$; $p < .001$; Lines: $k = 1.00$; $p < .001$) and autistic participants (Representational: $k = 0.93$; $p < .001$; Circles: $k = 1.00$; $p < .001$; Lines: $k = 1.00$; $p < .001$).

Results

Data generated by the battery of standardised assessments and experimental tasks were analysed via generalised linear mixed effects models and linear mixed effects models using the glmer and lmer functions from the lme4 package in R (Bates et al., 2015), or multiple regression models. All mixed-effects models contained by-participant and by-item random intercepts to account for variation across participants and stimuli. Population was coded as 0 (NT) and 1 (ASD). Receptive Language, Expressive Language and Fine Motor Skills were coded as the participant's age equivalent score on the corresponding modules of the Mullen Scales of Early Learning. Non-verbal Intelligence was coded as the participant's raw score on the Leiter-3. CARS Score was coded as the participant's total score on the CARS-2. Chronological Age was coded as the participant's age in months. Free Play and Birthday Party were coded as the participant's raw scores on the adapted ADOS symbolic play tasks. Picture Comprehension was coded as the participant's raw score on the Picture Comprehension task, and both trial types (Same Labels and Contrasting Labels) were coded as 0–3. Picture Production was coded as the participant's raw score on the Picture Production task, and both trial types (Modelled and Unmodelled) were coded as 0–3. Social Communication was coded as the participant's total score on the adapted ADOS social-communication task, and each individual trial was coded as either 0–3 (Response to Name, Response to Joint Attention, Social Smile) or 0–1 (Eye Contact, Giving and Initiation of Joint Attention). Independent Drawing was coded as participant's raw score on the Free Draw Task. For each analysis, we started with a baseline model containing only by-participant and by-item random intercepts to account for variation across participants and stimuli random effects. Fixed effects were added individually, and we tested whether their inclusion significantly improved predictive fit. Please refer to Appendix C for full details of the model building processes for all analyses.

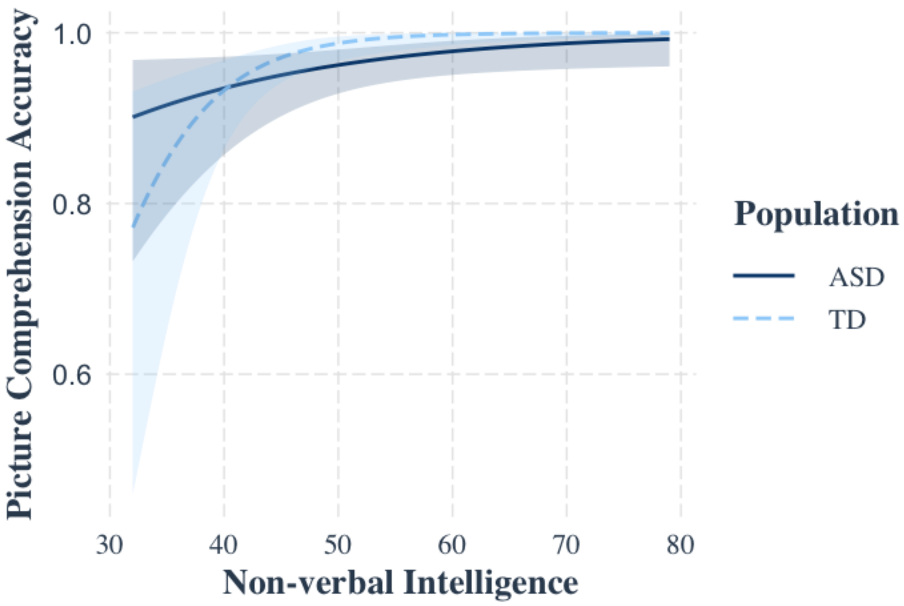
Picture Comprehension

Trial Number was coded 1–16, based on the order of trial administration, and was tested as a fixed effect to rule out practice effects. Accuracy was coded as 0 (incorrect) and 1 (correct). The mean score in the Contrasting Labels Condition was 0.97 (SD = 0.42) for autistic children and 0.97 (SD = 0.16) for neurotypical children. The mean score in the Same Labels Condition was 0.92 (SD = 0.27) for autistic children and 0.93 (SD = 0.25) for neurotypical children. The likelihood of responding correctly by chance was 50%. Trial Type was contrast coded as -0.5 (Contrasting Labels Condition) and +0.5 (Same Labels Condition). The analysis included 864 trials in total.

A model containing Population, Non-verbal Intelligence, and Population x Non-verbal Intelligence provided the best fit to the observed data (see Table 2). The Population x Non-verbal Intelligence interaction is visualised in Figure 3. This interaction was deconstructed by testing the effect of Non-verbal Intelligence on the autistic and neurotypical children separately. Neurotypical children (Z = 4.17, p < .001) and autistic children (Z = 2.45, p = .015) were both significantly more likely to correctly identify the depicted target object as non-verbal intelligence increased, with the predictive effect being notably larger for neurotypical children than autistic children. Autistic children with lower Non-verbal Intelligence scores responded more accurately than neurotypical children with lower Non-verbal Intelligence scores. However, as Non-verbal Intelligence scores increased differences between the groups disappeared, with both achieving ceiling-level accuracy.

Figure 3

Visualisation of the Population x Non-verbal Intelligence interaction, including the final model predicting Picture Comprehension accuracy



Note. X axis reflects Leiter-3 raw score, rather than IQ

Table 2

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of children's picture comprehension accuracy, predicted by Population, Non-verbal Intelligence, and Population x Non-verbal Intelligence

Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	-4.41	2.37	-1.87	.063
Population	4.79	2.76	1.74	.083
Non-verbal Intelligence	0.18	0.05	3.25	.001*
Population x Non-verbal Intelligence	-0.12	0.06	-1.95	.051
	AIC	BIC	logLik	deviance
	325.0	353.6	-156.5	313.0

Picture Production

Trial Number was coded 1–6, based on the order of trial administration, and was tested as a fixed effect to rule out practice effects. Accuracy was coded as 0 (incorrect) and 1 (correct). For autistic children, the mean score in the Unmodelled Trials Condition was 0.56 (*SD* = 0.50) and the mean score in the Modelled Trials Condition was 0.70 (*SD* = 0.46). For neurotypical children, the mean score in the Unmodelled Trials Condition was 0.58 (*SD* = 0.50) and the mean score in the Modelled Trials Condition was 0.69 (*SD* = 0.46). Trial Type was contrast coded as -0.5 (Unmodelled Trials Condition) and +0.5 (Modelled Trials Condition). The analysis included 324 trials in total.

A model containing Population, Chronological Age, Population x Chronological Age, and Population x Giving provided the best fit to our observed data (see Table 3). These results indicate a borderline significant tendency that autistic children achieved higher Picture Production scores than neurotypical children. The Population x Chronological Age and Population x Giving interactions were deconstructed by testing the effects of chronological age and Giving on the autistic and neurotypical children separately. Autistic children who scored 0 for Giving achieved significantly higher Picture Production scores than children who scored 1 ($Z = -2.81$, $p = .005$). Conversely, neurotypical children who scored 1 for Giving achieved significantly higher Picture Production scores ($Z = 3.58$, $p = .001$). The Population x Chronological Age interaction is visualised in Figure 4. For both neurotypical children ($Z = 5.18$, $p < .001$) and autistic children ($Z = 3.92$, $p < .001$), picture production accuracy increased with chronological age, however the effect was steeper for neurotypical children. Autistic children achieved ceiling-level accuracy at a much older age in comparison to neurotypical children.

Figure 4

Visualisation of the Population x Chronological Age interaction, including the final model predicting Picture Production accuracy

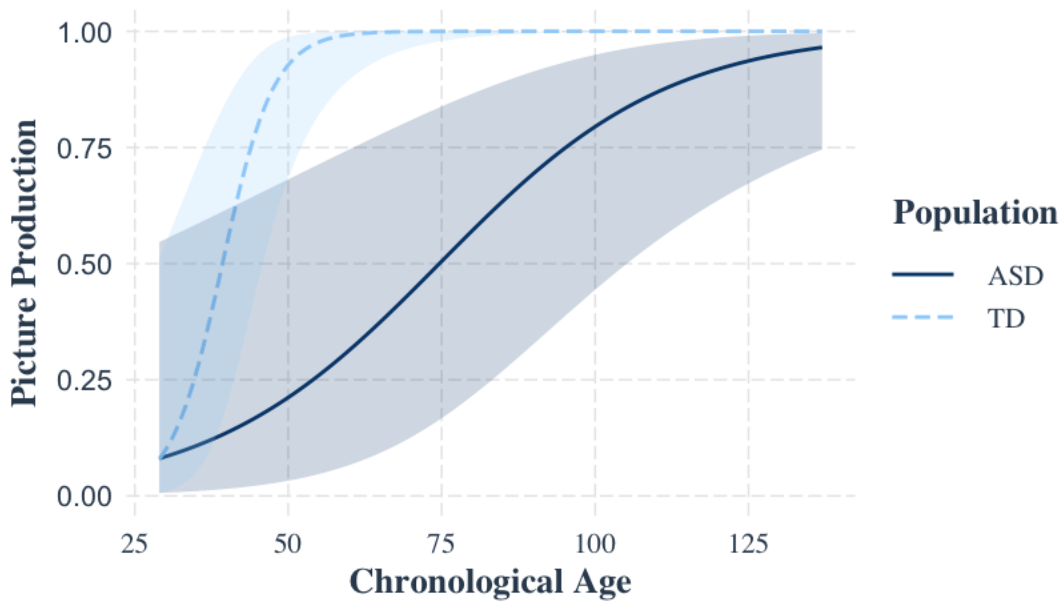


Table 3

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of children's picture production accuracy, predicted by Population, Chronological Age, Giving, Population x Chronological Age, and Population x Giving

Fixed effects	Estimated coefficient	Std. error	Z	Pr(>|z|)
(Intercept)	-9.87	3.15	-3.14	.002*
Population	6.56	3.44	1.91	.056
Chronological Age	0.24	0.07	3.38	.001*
Giving	3.39	1.26	2.70	.007*
Population x Chronological Age	-0.19	0.07	-2.55	.011*
Population x Giving	-7.94	2.46	-3.23	.001*
	AIC	BIC	logLik	deviance
	304.9	335.2	-144.5	288.9

Free Play

Based on the participant's raw scores on the adapted ADOS Free Play task, Total Toys was coded 0–13 (ASD: *M* = 4.63, *SD* = 1.42; NT: *M* = 6.56, *SD* = 1.91), Highest Level of Play was coded 0–2 (ASD: *M* = 1.19, *SD* = 0.62; NT: *M* = 1.74, *SD* = 0.45), and all of the following measures were coded 0–1: Uses Toys as Agents (ASD: *M* = 0.22, *SD* = 0.42; NT: *M* = 0.63, *SD* = 0.49), Object Substitution (ASD: *M* = 0.19, *SD* = 0.40; NT: *M* = 0.59, *SD* = 0.50), Unusual Sensory Interest (ASD: *M* = 0.41, *SD* = 0.50; NT: *M* = 0.04, *SD* = 0.19), Adult Intervention Required (ASD: *M* = 0.81, *SD* = 0.40; NT: *M* = 0.44, *SD* = 0.51) and Imitates Modelled Play (ASD: *M* = 0.37, *SD* = 0.49; NT *M* = 0.26, *SD* = 0.45).

As participants contributed only one data point each, relationships between measures of play and participant individual differences were explored via multiple regression modelling rather than mixed-effects modelling, with comparisons drawn between models of varying complexity to identify the most parsimonious and best-fitting explanation for each dependent variable. Each analysis started by entering population as an individual fixed effect. The second block of models tested individual Population x [Chronological Age, Receptive Language, Expressive Language, Fine Motor Skills, Non-verbal Intelligence, CARS Score, Birthday Party, Social Communication, Response to Name, Response to Joint Attention, Social Smile, Eye Contact, Giving, Initiation of Joint Attention, Picture Comprehension, Same Labels Trials, Contrasting Labels Trials, Picture Production, Modelled Trials, Unmodelled Trials, and Independent Drawing] interactions. In the third block of models, if multiple interactions were significant, these were added into the same model, and we tested whether their inclusion yielded a significant improvement in predictive fit over the models containing individual interactions. The final model for each dependent variable represents the most parsimonious and best-fitting explanation for the data, and only included fixed effects that led to significant improvements in predictive fit when combined.

Total Toys

Total Toys was best predicted by a model that included Population (β = 9.48, p = .026), Eye Contact (β = 2.29, p = .013), Contrasting Labels Trials (β = 1.68, p = .001), Population x Eye Contact (β = -2.51, p = .039), and Population x Contrasting Labels Trials (β = -1.25, p = .027), $F(5, 48) = 9.42$, $p < .001$, adjusted $R^2 = 0.44$. These interactions were deconstructed by testing the effects of Eye Contact and Contrasting Labels Trials on the autistic and neurotypical children separately. The Population x Eye Contact interaction showed that, for neurotypical children, Total Toys score increased as Eye Contact increased (t = 2.31, p =.029), whereas there was no relationship between Eye Contact and Total Toys score for autistic children (t = -0.19, p = .847). The Population x Contrasting Labels Trials showed that, for neurotypical children, Contrasting Labels Trials accuracy increased as Total Toys score increased (t = 3.17, p = .004), whereas for autistic children there was no relationship between Contrasting Labels Trials accuracy and Total Toys score ($t = 1.85$, $p = .076$).

Highest Level of Play

Highest Level of Play was best predicted by Population ($\beta = -0.56$, $p < .001$), $F = 14.20$, $p < .001$. Autistic children were significantly less likely to engage in symbolic play than neurotypical children.

Uses Toys as Agents

Uses Toys as Agents was best predicted by a model that included Population ($\beta = 0.73$, $p = .150$), Social Communication ($\beta = 0.12$, $p = .011$) and Population x Social Communication ($\beta = -0.12$, $p = .045$). This interaction was deconstructed by testing the effect of Social Communication on the autistic and neurotypical children separately. For neurotypical children, higher Social Communication scores were associated with an increased likelihood of using toys as agents during independent free play ($t = 2.61$, $p =.015$), whereas there was no relationship between Social Communication scores and using toys as agents for autistic children ($t = 0.23$, $p = .824$).

Object Substitution

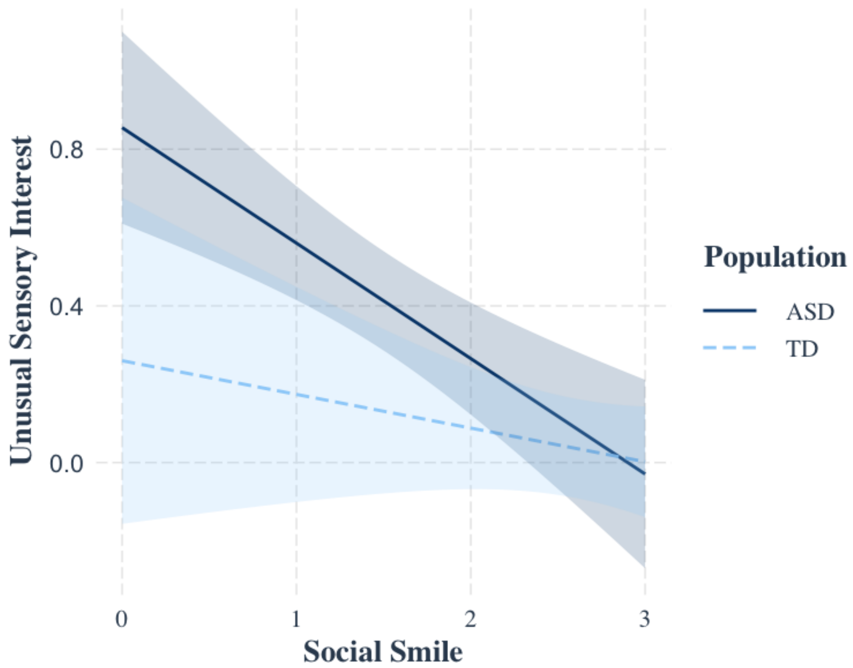
Object Substitution was best predicted by a model that included Population ($\beta = 0.65$, $p = .192$), Social Communication ($\beta = 0.12$, $p = .013$) and Population x Social Communication ($\beta = -0.11$, $p = .045$). This interaction was deconstructed by testing the effect of Social Communication on the autistic and neurotypical children separately. For neurotypical children, higher Social Communication scores were associated with an increased likelihood of exhibiting object substitution during independent free play ($t = 2.44$, $p =.022$), whereas there was no relationship between Social Communication scores and Object Substitution for autistic children ($t = 0.44$, $p = .662$).

Unusual Sensory Interest

Unusual Sensory Interest was best predicted by a model that included Population (β = 0.60, p = .017), Social Smile (β = -0.09, p = .264) and Population x Social Smile (β = -0.21, p = .047). This interaction was deconstructed by testing the effect of Social Smile on the autistic and neurotypical children separately. For autistic children, Social Smile score increased as Unusual Sensory Interests decreased (t = -3.30, p =.003), whereas there was a borderline significant relationship between Social Smile scores and Unusual Sensory Interests for neurotypical children (t = -2.04, p = .053). Neurotypical children who scored lower on Social Smile were less likely to exhibit unusual sensory interests than autistic children who scored lower on Social Smile. As Social Smile increased, differences between populations diminished. This interaction is visualised in Figure 5.

Figure 5

Visualisation of the Population x Social Smile interaction, including the final model predicting Unusual Sensory Interest



Adult Intervention Required

Adult Intervention Required was best predicted by a model that included Population (β = -1.01, p = .035), Social Communication (β = -0.16, p = .001) and Population x Social Communication (β = 0.14, p = .013), F(3, 50) = 8.36, p < .001, adjusted R^2 = 0.29. This interaction was deconstructed by testing the effect of Social Communication on the autistic and neurotypical children separately. For neurotypical children, higher Social Communication scores were associated with a decreased likelihood of requiring adult intervention during independent free play (t = -3.57, p = .001), whereas there was no relationship between Social Communication scores and requiring adult intervention for autistic children (t = -0.81**,** p = .424).

Imitates Modelled Play

Imitates Modelled Play was best predicted by a model that included Population (β = 4.42, p = .025), Same Labels Trials (β = -0.04, p = .760) and Population x Same Labels Trials (β = -0.55, p = .029), (β = -0.16, p = .001), F(3, 50) = 3.12 p = .034, adjusted R^2 = 0.11. The Population x Same Labels Trials interaction showed that, for autistic children, higher scores on Same Labels Trials were associated with decreased likelihood of imitating play actions modelled by the experimenter (t = -2.98, p = .006), whereas there was no relationship between Same Labels Trials score and Imitates Modelled Play for neurotypical children (t = -0.30, p = .767).

Birthday Party

The following variables were coded 0–1: Putting Candles on Cake, Singing Happy Birthday, and Giving Baby a Drink. The following variables were coded 0–3: Blowing out Candles, Feeding Baby, Cleaning Up, and Putting Baby to Bed. Relationships between these measures of play and participant individual differences were explored via generalised linear mixed-effects modelling for 0–1 pass/fail trials, and linear mixed-effects modelling for 0–3 experimenter-scaffolded trials. The maximum total score for the Birthday Party task was 15 (ASD: $M = 10.39$, $SD = 1.95$; NT: $M = 12.81$, $SD = 1.64$). The analysis included 378 trials in total.

0–1 Trials (Putting Candles on Cake, Singing Happy Birthday, Giving Baby a Drink)

The inclusion of fixed effects did not improve model fit.

0–3 Trials (Blowing out Candles, Feeding Baby, Cleaning Up, and Putting Baby to Bed)

A model containing Population, Fine Motor Skills, Free Play, Population x Fine Motor Skills, and Population x Free Play provided the best fit to our observed data (see Table 4). Neurotypical children were significantly more likely to attain higher scores on 0–3 Birthday Party trials than autistic children. However, these effects were qualified by interactions with Fine Motor Skills and Free Play, which are visualised in Figures 6 and 7. These interactions were deconstructed by testing the effects of fine motor skills and free play on the autistic and neurotypical children separately. Autistic children with more developed fine motor skills achieved higher scores on 0–3 Birthday Party trials ($t = 3.84$, $p < .001$), whereas fine motor skills did not have a significant predictive effect on neurotypical children's performance ($t = 0.56$, $p = .581$). Autistic children who scored higher on Free Play achieved significantly higher scores on 0–3 Birthday Party trials ($t = 2.06$, $p = .042$) while Free Play had no significant influence on the performance of neurotypical children ($t = -0.23$, $p = .823$)

Figure 6

Visualisation of the Population x Fine Motor interaction, included in the final model predicting performance on 0–3 Birthday Party trials

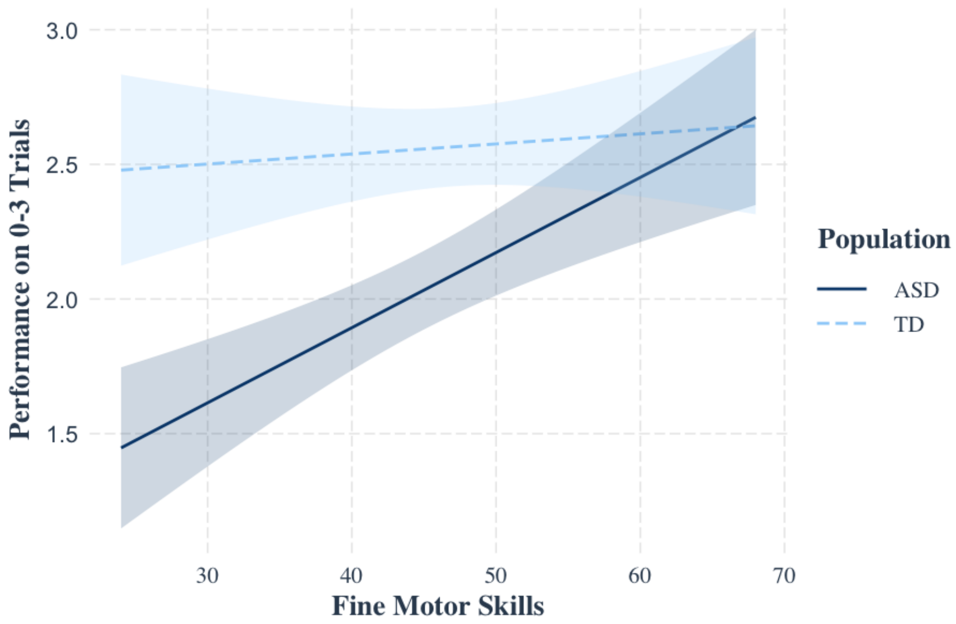


Figure 7

Visualisation of the Population x Free Play interaction, included in the final model predicting performance on 0–3 Birthday Party trials

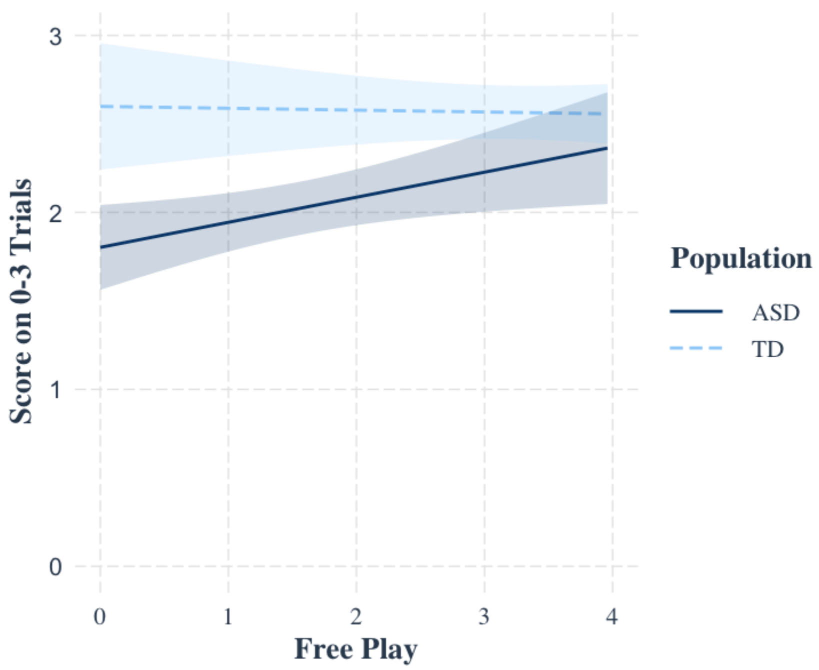


Table 4

Summary of the fixed effects in the final generalised linear mixed-effects model (log odds) of children's performance on 0–3 trials, predicted by Population, Fine Motor Skills, Free Play, Population x Fine Motor Skills, and Population x Free Play

Fixed effects	Estimated coefficient	Std. error	*t*	$\Pr(>\lvert z\rvert)$
(Intercept)	2.41	0.35	6.97	< .001
Population	-1.88	0.46	-4.07	< .001
Fine Motor Skills	0.00	0.01	0.60	.547
Free Play	-0.02	0.05	-0.35	.723
Population x Fine Motor Skills	0.02	0.01	2.49	.014
Population x Free Play	0.16	0.08	2.16	.032
	AIC	BIC	logLik	deviance
	509.2	536.2	-246.6	493.2

Social Communication

Based on the participant's raw score on the corresponding modules of the adapted ADOS social-communication tasks, Response to Name (ASD: *M* = 2.22, *SD* = 0.93; NT: *M* = 2.93, *SD* = 0.38), Response to Joint Attention (ASD: *M* = 1.89, *SD* = 0.70; NT: *M* = 2.70, *SD* = 0.54), and Social Smile (ASD: *M* = 1.52, *SD* = 0.94; NT: *M* = 2.59, *SD* = 0.84) were coded 0–3, and Eye Contact (ASD: *M* = 0.15, *SD* = 0.36; NT: *M* = 0.89, *SD* = 0.32), Giving (ASD: *M* = 0.07, *SD* = 0.27; NT: *M* = 0.22, *SD* = 0.42), and Initiation of Joint Attention (ASD: *M* = 0.26, *SD* = 0.59; NT: *M* = 0.26, *SD* = 0.59) were coded 0–1.

As participants contributed only one data point each, relationships between measures of social communication and participant individual differences were explored via multiple regression modelling rather than mixed-effects modelling, as described for the preceding analysis of Free Play.

Response to Name

Response to Name was best predicted by Population (*β* = -0.70, p = .001), $F(1, 52) = 13.11$, p = .001, adjusted R^2 = 0.19. Autistic children were significantly less likely to respond with eye contact when their name was called by the experimenter than neurotypical children.

Response to Joint Attention

Response to Joint Attention was best predicted by Population (*β* = -0.81, $p < .001$), $F(1, 52) = 22.96$, $p < .001$, adjusted R^2 = 0.29. Autistic children were significantly less likely to follow the experimenter's eye gaze or point towards a distal referent than neurotypical children.

Social Smile

Social Smile was best predicted by a model that included Population (*β* = -4.90, $p < .001$), Chronological Age (*β* = -0.04, p = .056), and Population x Chronological Age (*β* = 0.07, p = .005), $F(3, 50) = 16.68$, $p < .001$, adjusted R^2 = 0.47. Autistic children were significantly less likely to score a 1 in the Social Smile task than neurotypical children. For neurotypical children, there was no relationship between social smiling and Chronological Age (t = -1.83, p =.080), whereas for autistic children social smiling increased as Chronological Age increased (t = 4.70, $p < .001$).

Eye Contact

Eye Contact was best predicted by Population (*β* = -0.74, $p < .001$), $F(1, 52) = 63.41$, $p < .001$, adjusted R^2 = 0.54. Autistic children were significantly less likely to exhibit typical eye contact than neurotypical children.

Giving

The inclusion of fixed effects did not improve model fit.

Initiation of Joint Attention

The inclusion of fixed effects did not improve model fit.

Discussion

The present study investigated whether predictive relationships between social, pictorial, and play domains differ for language-matched autistic and neurotypical children. Across populations, differences in the presence, direction, and magnitude of predictive relationships between symbolic domains were identified. Although social communication skills predicted play and pictorial abilities, and vice versa, in neurotypical children, these relationships were not observed in autistic children. Evidence for possible relationships between play and pictorial domains were identified in neurotypical children, but not autistic children. Despite being matched on language, social communication scores were consistently lower for the autistic group than the neurotypical group. Together, these findings suggest that relationships between social communication and non-linguistic symbolic domains may be different in ASD, and that the modules are relatively more independent in autism.

Across populations, children's picture comprehension accuracy did not significantly differ, indicating that picture-object matching abilities in our autistic sample were at the level expected based on their language skills. However, while non-verbal intelligence was identified as a significant predictor of variability in both populations, autistic children with lower non-verbal intelligence appeared to respond more accurately than neurotypical children with lower non-verbal intelligence. Considering the non-verbal, highly visual format of the Leiter-3 assessments, and the visual-perceptual matching required in our picture comprehension task, this could potentially reflect more naturally honed visual perception abilities in the autistic population, due to their enhanced perceptual functioning and greater attention to detail (Auyeung et al., 2008; Mottron et al., 2006, 2013). Indeed, autistic children reliably outperform neurotypical controls during visual tasks with brief presentations (Plaisted et al., 1998; O'Riordan et al., 2001). As our picture-object matching task specifically manipulated the availability of linguistic scaffolding, an absence of trial type across populations suggests that autistic and neurotypical children utilised linguistic scaffolding in similar ways to correctly identify the depicted target objects in both conditions. That is, both groups of children focussed on iconicity, rather than relying on language, to solve both trial types. Overall, our findings demonstrate comparable picture comprehension abilities across language-matched populations, indicating that this ability is not a specific area of weakness or difference for autistic children (when expectations are based on their developmental level, rather than age).

Across populations, the likelihood of achieving higher picture production scores was associated with older chronological age and children who spontaneously gave items to others. However, these effects were qualified by significant Population x Chronological Age and Population x Giving interactions. For both populations, picture production accuracy increased with chronological age, however, the effect was steeper for neurotypical children. This could potentially reflect an advantage in developmental experience and possibly more time spent watching others draw and assimilating effective strategies. Autistic children achieved ceiling-level accuracy at a much older age in comparison to neurotypical children. As pictures are cultural conventions acquired through social interactions with others (Callaghan et al., 2011, 2012), and autistic children spend less time engaged in social activities than their neurotypical peers (Ruble & Robson, 2007), it is possible that autistic children take longer to accumulate equivalent experience of watching others produce graphic representations and learning through collaborative social experiences to perform at ceiling on our task. Autistic children who did not exhibit spontaneous giving achieved significantly higher picture production scores than children who did. Conversely, neurotypical children who voluntarily gave items to others achieved significantly higher picture production scores. This unexpected finding requires further investigation to understand.

During independent free play, neurotypical children were significantly more likely to engage in symbolic play than autistic children. This is congruent with previous evidence demonstrating delays and difficulties in symbolic play skills in ASD (Hobson et al., 2015; Jarrold, 2003; Thiemann-Bourque et al., 2019; Wetherby et al., 2004). In the neurotypical group, higher social communication scores were associated with an increased likelihood of attributing agency to toys and exhibiting object substitutions during free play. These findings highlight a possible link between social understanding and symbolic play in neurotypical children, indicating that social communication may support play, which substantiates previous evidence indicating inter-domain relationships between social skills and non-linguistic symbolic domains in this population (Carter & Hartley, in prep a, see Chapter 2). In contrast, no relationships were identified between social communication scores and symbolic play skills for the autistic group, suggesting a potential independence of these domains in ASD. For neurotypical children, interacting with a higher number of toys during independent free play was predicted by increased eye contact with the examiner and greater picture comprehension accuracy. However, there was no relationship between these measures for autistic children. It is possible that neurotypical children perceived this interaction with toys as being a more social opportunity and were therefore more likely to look to the experimenter for reassurance or permission to continue exploring the full range of toys, while the autistic children were more inclined to explore the toys without attending to the experimenter and seeking non-verbal signs of encouragement. The predictive effect of picture comprehension indicates a link between play and picture domains in typical children, but not autistic children, which provides tentative support for the theory that symbolic development may be underpinned by qualitatively different learning mechanisms in ASD (Mundy, 1995).

In the Birthday Party task, there was no difference between the populations for any effects on the pass/fail trials (coded 0–1) that involved singing “Happy Birthday”, putting candles on a cake, and giving a baby doll a drink. However, in the experimenter-scaffolded trials (coded 0–3) which involved blowing out candles, feeding a baby doll, cleaning up a spillage and putting a baby doll to sleep, neurotypical children were significantly more likely to attain higher scores than autistic children. However, this effect was qualified by significant Population x Chronological Age and Population x Giving interactions. Autistic children with more developed fine motor skills achieved higher scores on 0–3 Birthday Party trials, whereas fine motor skills did not have a significant predictive effect on neurotypical children's performance. This association could be attributed to the high prevalence of fine motor difficulties frequently observed in ASD (Bhat et al., 2011; Green et al., 2009), and reflect marginally more advanced fine motor skills in our neurotypical group, as these tasks involved object manipulation using fingers and hands. Autistic children who scored higher on Free Play achieved significantly higher scores on 0–3 Birthday Party trials, which reflects a within domain link, while Free Play had no significant influence on the performance of neurotypical children. For the autistic group, who show more variability in their symbolic play abilities, this suggests that low performance in one area of play (e.g. independent free play) is indicative of low performance in other specific aspects of symbolic play. The lack of relationship for neurotypical children possibly reflects the lack of variability in symbolic play skills, as this is not generally delayed or different in this population.

Compared to neurotypical children, autistic children were significantly less likely to: i) exhibit typical eye contact, ii) follow the experimenter's eye gaze or point towards a distal referent, iii) respond with eye contact when their name was called by the experimenter, and iv) smile socially in response to the experimenter. These findings are unsurprising, given the well-documented challenges associated with ASD – notably in social-motivation and social-cognition (Carpenter et al., 2001; Chevallier et al., 2012; DSM-V; American Psychiatric Association, 2013). Across populations, older children were less likely to socially smile compared to younger children. However, these effects were qualified by an interaction. For neurotypical children, there was no relationship between social smiling and Chronological Age, whereas for autistic children social smiling increased as Chronological Age increased. Considering that many autistic children receive one-to-one support and targeted interventions from teaching assistants (Groom & Rose, 2005), this could reflect increased familiarity, and compliance, with the "hidden curriculum" of social norms that all individuals are expected to know, but are not usually directly taught (Heerey et al., 2005; Myles, 2005).

Across populations, children who attained higher Picture Production scores were significantly more likely to spontaneously give items to the experimenter during independent free play than those who achieved low Picture Production scores. However, these effects were qualified by an interaction. For neurotypical children, spontaneous giving increased as Picture Production score increased, whereas for autistic children there was no relationship between Picture Production score and Giving. Initiation of Joint Attention was not predicted by any of the social skills or individual differences across participants. While this finding is somewhat unusual/unexpected, this could reflect a difficulty in capturing children's joint attention abilities based on a very narrow window of opportunity to initiate joint attention during the ADOS. Capturing a measure of IJA in a more naturalistic setting may be more appropriate for future research.

While the current study has examined within-child abilities and characteristics, it is not clear how environmental effects could influence this, such as access to interventions. This would be useful to investigate within the context of a longitudinal study. As most of the skills we are interested in develop very early in childhood, and ASD is most frequently diagnosed at 4 years (Daniels & Mandell, 2013), we recommend that future studies recruit infants with an increased likelihood of developing ASD and assess their symbolic development *pre-diagnosis*. Owing to genetic heredity, one-in-five younger siblings of autistic individuals are diagnosed as autistic themselves, and one-in-three manifest sub-clinical differences indicative of the broader autism phenotype (Ozonoff et al., 2011). By assessing these children from 24 months, future studies could effectively chart how ASD impacts early symbolic development prior to formal diagnosis.

Overall, our study identifies differences in the direction and magnitude of predictive relationships between symbolic domains in matched samples of neurotypical children and autistic children. In neurotypical development, relationships between pictures and social communication emerged, and play was positively predicted by pictures and social communication. These findings indicate a potential interdependence between modules of symbolic development and implicate social communication as a common underpinning factor in supporting non-linguistic symbolic domains for neurotypical children. This is consistent with domain-general accounts of symbolic development (Piaget, 1952). In contrast, our results suggest that symbolic domains are relatively independent in autistic children, thus aligning with domain-specific accounts (Chomsky, 1957). From a practical perspective, our findings could help to inform the design and delivery of clinical and educational interventions targeting symbolic development in ASD.

Chapter 5: Are children with autism more likely to retain object names when learning from colour photographs or black-and-white cartoons?

Chapter Introduction

Considering the prevalence of language difficulties among autistic children who often rely on picture-based communication, it is crucial to investigate the factors that influence their ability to learn words from visual stimuli. Previous research indicates that minimally verbal autistic children may have difficulty understanding symbolic relationships between words, pictures, and objects (Hartley & Allen, 2014a, 2015a, 2015b; Preissler, 2008), but their performance is mediated by iconicity. However, no prior studies have examined autistic children's retention of novel words learned from pictures beyond initially mapping. This chapter presents a study that seeks to examine the impact of autism spectrum disorder on children's ability to acquire vocabulary from varying visual stimuli, specifically contrasting colour photographs with black-and-white cartoons. This investigation is integral for elucidating the cognitive underpinnings of language acquisition in autistic individuals and may inform the development of targeted interventions aimed at fostering their linguistic development. Note that all autistic and neurotypical children in this study also participated in studies 1 and 2.

Author Contribution: *Cheriece Carter*: design, data collection, analysis, writing, review. *Calum Hartley*: design, analysis, review.

Published as*: Carter, C.K., & Hartley, C. (2021). Are children with autism more likely to retain object names when learning from colour photographs or black-and-white cartoons? *Journal of Autism and Developmental Disorders*, *51*(9), 3050–3062. https://doi.org/10.1007/s10803-020-04771-2

* Please note that minor adjustments have been made to the language in this chapter to reflect the shift to identity-first language after its publication.

Abstract

For the first time, this study investigated whether autistic children and neurotypical children matched on language comprehension (*M* age equivalent = ~44 months) are more likely to retain words when learning from colour photographs rather than black-and-white cartoons. Participants used mutual exclusivity to fast map novel word-picture relationships and retention was assessed following a 5-min delay. Autistic children achieved significantly greater retention accuracy when learning from photographs than cartoons and, surprisingly, responded more accurately than neurotypical children when learning from photographs. Our results demonstrate that autistic children benefit from greater iconicity when learning words from pictures, providing a data-grounded rationale for using colour photographs when administering picture-based interventions.

Introduction

Language acquisition is a crucial developmental milestone that underpins children's cognitive and social development (Carpenter et al., 1998; Tomasello, 2003b; Vygotsky, 1962). Effective communication and engagement with the social world is facilitated by a child's capacity to learn words, a skill which can be profoundly delayed or different in autism spectrum disorder (ASD; Tager-Flusberg & Kasari, 2013). While the onset of speech in neurotypical (NT) children occurs around 12–18 months (Tager-Flusberg et al., 2009; Zubrick et al., 2007), many autistic children experience delays in acquiring language, often producing their first words around 36–38 months (Anderson et al., 2007; Howlin et al., 2009). Although the majority of autistic individuals develop functional language skills over the school years (Pickles et al., 2014), approximately 25–30% remain minimally verbal or non-verbal (Bal et al., 2016; Norrelgen et al., 2015; Tager-Flusberg & Kasari, 2013). Many of these children are taught to communicate using the Picture Exchange Communication System (PECS; Bondy & Frost, 1994), however, research suggests that autistic children with concomitant language difficulties can struggle with understanding symbolic relationships between words, pictures, and objects (Hartley & Allen, 2014a, 2014b, 2015a, 2015b; Preissler, 2008). To inform the design and delivery of picture-based interventions, it is essential for research to explore how children acquire vocabulary from pictures. The purpose of the present study is to investigate how ASD impacts children's ability to learn words from pictures that vary on the dimension of iconicity – the extent to which a symbol resembles its intended referent.

To acquire vocabulary, children must associate the phonology and meaning of a word and form a lasting connection between the two. This process involves identifying a word's intended meaning (referent selection) and storing the word-referent pairing in memory for later retrieval (retention) and generalisation. Referent selection is complicated by the fact that there are often multiple potential targets for a newly-heard word (Quine, 1960) and requires children to direct their attention to a single target (the intended referent). By 2 years of age, NT children can overcome the challenge of referential ambiguity by applying the mutual exclusivity principle (i.e. the assumption that each referent only has a single label; Carey, 1978; Markman & Wachtel, 1988). Research has investigated children's use of this lexical heuristic by presenting a single unfamiliar object alongside one or more familiar objects and asking them to identify the referent of a novel word (Horst & Samuelson, 2008; Horst et al., 2010). As children already know the name(s) of the familiar object(s), they use mutual exclusivity to deduce that the novel word must refer to the unfamiliar object. However, NT 2-year-olds often forget new words just 5 minutes after performing at ceiling on mutual exclusivity referent selection tasks (Horst & Samuelson, 2008). Thus, it has been proposed that referent selection and retention are underpinned by separate 'fast mapping' and 'slow learning' processes (McMurray et al., 2012). 'Fast mapping' is the ability to rapidly associate a newly-heard word with a novel object by utilising linguistic and non-linguistic cues to figure out *what* the word refers to (Carey, 1978). 'Slow learning' refers to the activation of associative learning mechanisms that detect and accumulate statistical co-occurrences between words and environmental features over time and contexts (McMurray et al., 2012).

Several early studies attributed word learning difficulties in ASD to children's reduced responsiveness to social cues that support referent selection, such as gaze and pointing (e.g. Baron-Cohen et al.,1997; Preissler & Carey, 2005). However, a growing collection of research shows that many autistic children can utilise social-communicative cues to inform their referent selection (Bean Ellawadi & McGregor, 2016; Hani et al., 2013; Hartley et al., 2020; Luyster & Lord, 2009; McGregor et al., 2013). Furthermore, it is well-documented that children spanning the autism spectrum can use lexical heuristics, such as mutual exclusivity, to accurately identify the referents of unfamiliar words (de Marchena et al., 2011; Hartley et al., 2019). These findings raise the possibility that word learning could potentially be scaffolded by presenting visual and linguistic stimuli in a manner that appeals to the strengths of autistic children. Indeed, supporting referent selection appears to have positive effects on retention, as shown by correlations between these processes in NT children aged 18–30 months (Bion et al., 2013). In Hartley et al. (2019), accuracy on novel referent selection trials predicted children's receptive vocabulary, suggesting that facilitating referent selection could have long-term benefits for vocabulary acquisition.

While many studies have investigated how ASD influences fast mapping, relatively few have examined retention in this population. Norbury and colleagues (2010) demonstrated that verbal autistic children could retain word-object mappings as accurately as NT controls, but recalled fewer semantic details associated with novel words. In two recent papers, Hartley et al. (2019, 2020) found that autistic children with concomitant language difficulties retained novel word meanings acquired through fast mapping and cross-situational learning at least as accurately as vocabulary-matched NT controls after a 5-min break. These findings suggest that fundamental mechanisms supporting word learning, and the relationships between them, are not always qualitatively different in ASD.

Alongside words, pictures play an important role in supporting language acquisition and communication – they enable learning in the absence of direct experience. Shared picture book reading involves joint attention, pointing, and verbal labelling (Durkin, 1995), therefore providing a prime opportunity for children to learn the names of 3-D objects through exposure to their 2-D counterparts (Ninio & Bruner, 1978; Tomasello & Todd, 1983). Furthermore, augmentative and alternative communication interventions for autistic children predominantly use pictures to teach functional communication skills and encourage labelling (e.g. PECS; Bondy & Frost, 1994). However, in order to learn words from pictures, children must understand that pictures are not the only referents of their associated labels; labels paired with pictures actually refer to independently existing objects that pictures are intended to represent.

From an early age, NT children spontaneously map labels to depicted referents, demonstrating their understanding that pictures are symbolic representations and facilitating the extension of information to real objects (Baldwin, 1991; Baldwin et al., 1996; Ganea et al., 2008). Preissler and Carey (2004) examined this ability by teaching 18- and 24-month-olds the name of an unfamiliar object (a whisk) depicted in a black-and-white line drawing. Immediately after mapping, children were asked to identify the referent of the newly-learned word from an array consisting of the previously seen whisk picture and a previously unseen 3-D whisk. Both age groups consistently selected either the real object alone, or both the whisk-picture and the real whisk together. Despite the fact that the picture was the primary stimulus mapped to the word “whisk”, participants did not identify the picture as the sole referent of the label. These findings indicate that young NT children understand referential relationships between words, pictures, and the objects they represent (Ganea et al., 2008; Hartley & Allen, 2014a, 2015a).

However, learning in very young NT children is influenced by iconicity. According to Fuller’s (1997) taxonomy, highly-iconic symbols are “transparent” (e.g. colour photographs), moderately-iconic symbols are “translucent” (e.g. black-and-white drawings), and symbols with little or no resemblance to their referents are “opaque” (e.g. written words). Higher levels of perceptual similarity between picture and referent make the symbolic relationship more salient, increasing the likelihood that the viewer will map the correspondence and draw an inference from one to the other (DeLoache, 1995). This principle is supported by Ganea and colleagues (2008) who demonstrated that 15-month-olds could accurately extend labels from highly-iconic photographs to their corresponding objects, but not from less iconic cartoon pictures. Also, the degree with which young NT children can successfully imitate a sequence of actions following a picture-book reading interaction is mediated by iconicity (Simcock & DeLoache, 2006). When learning words from pictures, greater visual detail may lead to the formation of more robust representations of meaning during word-picture mapping, facilitating recognition of relationships between pictures and their referents when viewed independently (Ganea et al., 2008; Simcock & DeLoache, 2006).

Despite widespread use of picture-based interventions to support autistic individuals, relatively little research has investigated how autistic children comprehend pictures. To assess understanding of symbolic relationships between words, pictures, and objects, Preissler (2008) taught minimally verbal autistic children the word “whisk” in association with a black-and-white line drawing of a whisk. Unlike Preissler and Carey’s (2004) NT participants, the majority of autistic children thought the word “whisk” only applied to the picture and did not extend the label to the symbolised object. This striking difference suggests that minimally verbal autistic children have difficulty understanding symbolic word-picture-object relationships. These results are especially concerning given that minimally verbal autistic children are often taught names for 3-D objects via labelling their 2-D counterparts.

However, it is possible that Preissler’s (2008) participants were hindered by the iconicity of the pictorial stimuli. Hartley and Allen (2015a) tested this possibility by examining how minimally verbal autistic children extend labels from pictures that varied in iconicity. Their findings revealed that participants extended words to objects most accurately when taught using colour photographs. They also showed that autistic children were more likely to extend names to objects depicted in colour pictures than non-colour pictures. Together, these results suggest that iconicity has an important impact on symbolic understanding of pictures for autistic children with concomitant language difficulties (also see Hartley & Allen, 2014a, 2014b, 2015b, 2015c).

A shared feature of the aforementioned studies investigating children's understanding of word-picture-object relationships is their focus on fast mapping. Children are taught to associate a novel word with an unfamiliar picture and then presented with the opportunity to extend the label to the 3-D referent almost immediately after the word-picture relationship is established. However, this does not necessarily reflect how children learn from pictures in the real world. It is relatively uncommon to see a picture and then immediately encounter its referent; rather, a child might see a picture and hear its label on one occasion, but then be required to retrieve the representational meaning when they experience the symbolised referent on another occasion. For example, a child might first learn the meaning of "aeroplane" while looking at a picture of an aeroplane in a book, but then be required to recall the label shortly after while playing in the garden and seeing a real aeroplane fly overhead. Thus, the present study explores children's ability to *retain* novel words when learning from pictures and examines how iconicity influences this ability. As there are currently no data-grounded guidelines regarding which kinds of pictures should be used when delivering PECS, this study could strengthen the argument that highly-iconic colour pictures are most appropriate and effective.

The objective of this study is to investigate how ASD influences children's ability to learn words from pictures that vary in iconicity (e.g. colour photographs vs. black-and-white cartoons). Following a similar procedure as used in Hartley et al. (2019), autistic children and NT controls mapped novel word-picture relationships in a mutual exclusivity referent selection task. After a 5-min delay, children's retention of each word-referent pairing was assessed via two trial types. In 'picture trials', children were presented with the unfamiliar pictures that were named during the referent selection trials. In 'object trials', children were presented with the 3-D referents of pictures that were named during the referent selection trials. Based on previous evidence (e.g. Preissler & Carey, 2005), we predicted that both groups of children would correctly fast map new words to unfamiliar pictures in both conditions, but this might not be sufficient to support above-chance retention. In both participant groups, we expected to observe superior retention when learning words from highly-iconic colour photographs in comparison with less-iconic black-and-white cartoons. Importantly, this research addresses significant limitations of the existing literature by testing retention of words learned from pictures and probing children's understanding of what those words actually refer to. Our study is designed to better reflect children's real-life usage of pictures and bridge the methodological gap between research examining children's word learning from pictures and objects (Horst & Samuelson, 2008; Horst et al., 2010; McMurray et al., 2012). The findings will advance theoretical understanding by highlighting how learning from pictures impacts fast mapping and retention word learning mechanisms in both neurotypical and autistic development, and ascertain the influence of iconicity.

Method

Participants

Participants were 20 autistic children (14 males, 6 females; *M* age = 80.35 months, *SD* = 28.12) recruited from specialist schools, and 20 NT children (8 males, 12 females; *M* age = 41.55 months, *SD* = 7.17) recruited from mainstream nurseries (see Table 1). All children had normal or corrected-to-normal vision. Groups were matched on their receptive language skills, as measured by the Receptive Language module of the Mullen Scales of Early Learning (Mullen, 1995). Autistic children had a mean language comprehension age of 43.60 months (*SD* = 14.74) and NT children had a mean language comprehension age of 44.75 months (*SD* = 8.80), $t(38) = 0.30$, $p = .77$. Children's expressive language abilities were measured using the Expressive Language module of the Mullen Scales of Early Learning (Mullen, 1995). The expressive language age equivalents for autistic children (*M* = 37.70 months; *SD* = 19.41) and NT children (*M* = 44.95 months; *SD* = 10.52) did not significantly differ, $t(38) = 1.47$, $p = .15$. All autistic participants had previously obtained a clinical diagnosis from a qualified specialist, based on the criteria of standardised instruments (i.e. Autism Diagnostic Observation Schedule Version 2; Lord et al., 2012 and Autism Diagnostic Interview-Revised; Lord et al., 1994, Rutter et al., 2003) and expert judgment. Diagnoses were confirmed via the Childhood Autism Rating Scale Second Edition (CARS-2; Schopler et al., 2010), which was completed by each participant's class teacher (ASD: *M* score: 35.73, $SD = 4.38$; NT: *M* score: 16.03, $SD = 2.28$). Autistic children were significantly older ($t(38) = 5.98$, $p < .001$, $d = 1.89$), and had significantly higher CARS scores ($t(38) = 17.86$, $p < .001$, $d = 5.64$) than NT children. Children's non-verbal intellectual abilities were measured using the Leiter-3 (Roid et al., 2013). The mean (age-normed) IQ for the ASD group was 80.45 ($SD = 13.30$) and the mean IQ of the NT group was significantly higher at 102.25 ($SD = 6.66$), $t(38) = 6.56$, $p < .001$, $d = 2.07$. However, the groups' raw scores on the Leiter-3 did not significantly differ (ASD: *M* score: 54.80, $SD = 16.30$; NT: *M* score: 48.25, $SD = 4.84$), $t(38) = 1.72$, $p = .093$. All procedures performed in this study were in accordance with the ethical standards of institutional and national research committees. Informed consent was obtained from caregivers prior to their children's participation. None of the participants in the present study took part in similar studies recently conducted by the second author (e.g. Hartley et al., 2019, 2020).

Table 1

Sample characteristics (standard deviation and range in parentheses)

Population	*N*	Gender	Chron. age [months]	Mullen receptive language age equiv. [months]	Mullen expressive language age equiv. [months]	CARS-2 score	Leiter-3 IQ score	Leiter-3 raw score
NT	20	8 males, 12 females	41.55 (7.17; 30–53)	44.75 (8.80; 28–59)	44.95 (10.52; 26–62)	16.03 (2.28; 15–24)	102.25 (6.66; 87–113)	48.25 (4.84; 40–57)
ASD	20	14 males, 6 females	80.35 (28.12; 48–137)	43.60 (14.74; 22–69)	37.70 (19.41; 3–70)	35.73 (4.38; 30–45.50)	80.45 (13.30; 53–107)	54.80 (16.30; 36–107)

Note. NT: neurotypical; ASD: autism spectrum disorder; CARS-2: Childhood Autism Rating Scale Version 2

Materials

Stimuli included eight novel words (parloo, virdex, fiffin, modi, zepper, teebu, nelby, blicket) selected from the NOUN database (Horst & Hout, 2016), eight unfamiliar 3-D objects selected on the basis that children would not know their linguistic labels (see Figure 1), eight corresponding pictures of those unfamiliar objects (four allocated to the Cartoon condition, and four allocated to the Photograph condition), 11 black-and-white cartoon pictures of familiar objects, and 11 colour photographs of familiar objects. All pictures used in this study were laminated and measured 5cm x 5cm, which is the recommended sizing for PECS symbols (Frost & Bondy, 2002). Pictures of familiar objects were selected on the basis that most children understand their linguistic labels by 16 months (Fenson et al., 1994). The mean age of acquisition for familiar words in the Cartoon (M = 12.91) and Photograph (M = 12.73) conditions did not significantly differ, $t(10) = .24$, $p = .81$. A 12-megapixel camera was used to photograph each unfamiliar target object. Three colour photographs of familiar objects were used in the warm-up trials for the Photograph condition (dog, banana, tree). The remaining photographs of familiar objects were divided into pairs and presented alongside photographs of unfamiliar objects in referent selection trials (duck, bed, hand, ball, flower, car, cat, toothbrush). Black-and-white cartoon drawings of familiar and unfamiliar objects were created using Procreate software (version 5.0) on an iPad. Three cartoons of familiar objects were used in the warm-up trials for the Cartoon condition (bottle, key, aeroplane). The remaining cartoons of familiar objects were divided into pairs and presented alongside cartoons of unfamiliar objects in referent selection trials (bird, chair, apple, shoe, balloon, cup, teddy bear, hat).

Figure 1

Unfamiliar 3-D objects

Procedure

Our experimental task was very similar to that reported by Hartley et al. (2019). Participants were tested individually in their own educational settings and were accompanied by a familiar adult when required (e.g. key worker, teacher, or teaching assistant). Children were verbally praised for attention and good behaviour while completing measures of language comprehension, non-verbal intelligence, and word learning. These assessments took the form of fun “games” in separate sessions, on different days.

Word learning task

Children completed two within-subjects conditions – colour photograph and black-and-white cartoon – on different days. Order of administration was counterbalanced within populations (e.g. half of the autistic children received the Photograph condition first, and half received the Cartoon condition first). Each condition consisted of the following stages delivered in a fixed order: 1) warm-up trials, 2) referent selection trials, 3) test object familiarisation, 4) delay, 5) retention trials. The two conditions only differed in terms of the iconicity of pictures presented during the warm-up and referent selection stages.

Warm-up trials

Children were informed, “We’re going to play a game where I show you some pictures and ask you to find things…” To begin, all participants completed three warm-up trials; on each trial children were presented with three pictures of familiar objects (e.g. dog, banana, tree) and asked to identify one (e.g. “Which is the tree? Can you see the tree? Show me the tree.”). If children responded correctly, the experimenter issued praise and reinforced the identity of the object (e.g. “Well done, you found the tree!”). If children responded incorrectly, the experimenter provided corrective feedback (e.g. “Actually, this is the tree. Can you point to the tree? Well done, you found the tree!”). The experimenter then retrieved the pictures and re-ordered them for the next trial. Children were asked to identify a different picture in a different location (left, centre, middle) on each trial.

Referent selection trials

Immediately after the warm-up trials, children completed eight referent selection trials. These followed exactly the same format, except that the experimenter simply said “Thank you…” when children responded, and did not offer praise or corrective feedback.

Children were presented with four sets of pictures (each containing one picture of an unfamiliar object, and two pictures of familiar objects). Each set was presented twice; the experimenter requested the familiar object on one occasion (‘familiar trial’; e.g. “Which is the banana? Can you see the banana? Show me the banana.”) and the unfamiliar object on another occasion (‘unfamiliar trial’; “Which is the fiffin? Can you see the fiffin? Show me the fiffin.”). Familiar trials were included to deter children from always choosing the picture of the novel object and encourage them to examine every item in the array. Unfamiliar trials were designed to promote active learning of new word-picture pairings. As participants are likely to have known the labels for the two familiar pictures, they should apply the mutual exclusivity principle and deduce that the novel label refers to the picture of the unfamiliar object (Carey, 1978; Markman & Wachtel, 1988).

The order of trials was pseudo-randomised with the constraint that the same set of pictures was never presented on consecutive trials and no more than two trials of the same type (familiar or unfamiliar) were experienced sequentially. Positioning of objects (left, middle, right) was pseudo-randomised across trials with the constraint that the requested item did not appear in the same location more than twice consecutively. The four novel words were randomly allocated to the four unfamiliar pictures for each participant. Half of the novel words were always assigned to the Photograph condition (parloo, virdex, fiffin, modi) and the remaining words were always assigned to the Cartoon condition (zepper, teebu, nelby, blicket).

Test object familiarisation

Immediately after the final referent selection trial, children were familiarised with the as-yet unseen 3-D unfamiliar objects (depicted in the referent selection trials) before their appearance in the subsequent retention trials. The purpose of this stage was to minimise novelty and familiarity preferences, increasing the likelihood that children would select items based on their memory of word-picture mappings. The experimenter presented an unfamiliar 3-D object with a named picture of a different unfamiliar object and then gave a verbal instruction to “look!”. Children were allowed to touch the objects if they wished. After approximately 5 seconds, the experimenter removed the pair of items from view and presented the next pair until all of the novel objects had been seen. Picture-object pairings were fixed and children received one of two presentation orders. Positioning of items to the left and right was randomised.

Delay

Immediately after the final test object familiarisation trial, the experimenter removed all experimental stimuli from the child’s view and initiated a new and unrelated game for 5 minutes.

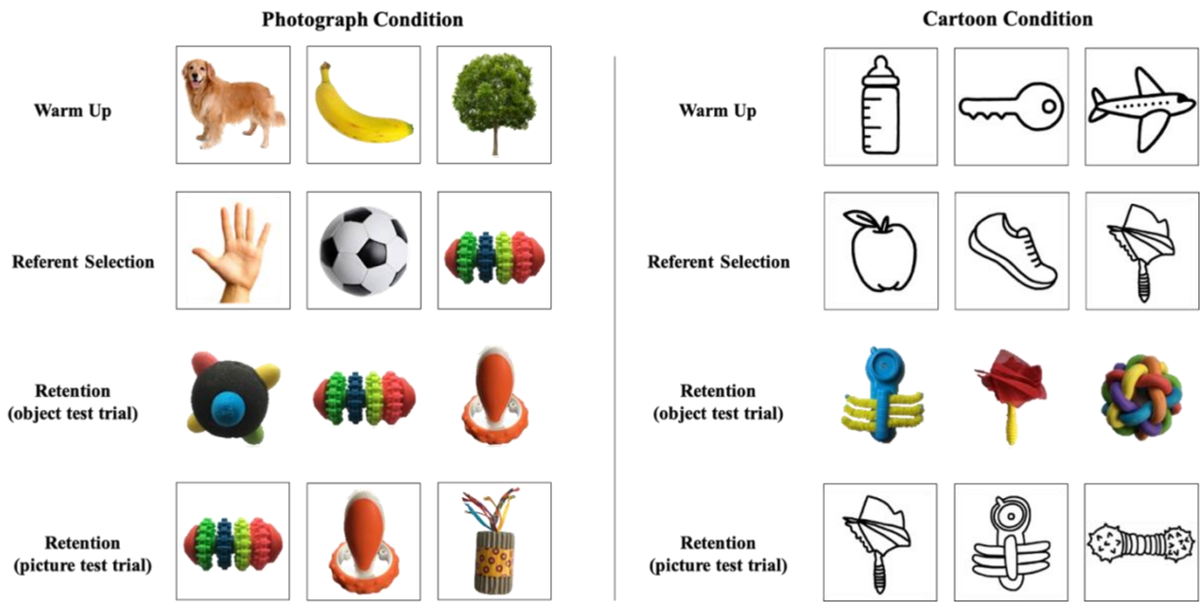
Retention trials

To re-engage children’s attention to the task, the experimenter administered one warm-up trial as described above. Eight retention trials immediately followed (see Figure 2 for an illustration of each trial type). Children’s memory of each word-referent pairing was tested twice (once in each modality: picture and object). For picture retention trials, three pictures of unfamiliar objects that were named during the referent selection trials were presented on the table in front of the child in a row (left, centre, right). The experimenter asked children to identify one of the pictures (e.g. “Which is the parloo? Can you see the parloo? Show me the parloo.”). The purpose of these trials was to assess children’s memory of the exact word-referent pairings that were experienced during the referent selection trials. For object retention trials, three unfamiliar objects that were symbolised by pictures that were named in the referent selection trials were presented on the table in front of the child in a row (left, centre, right). The experimenter asked children to identify one of the objects (e.g. “Which is the virdex? Can you see the virdex? Show me the virdex.”). The purpose of these trials was to assess whether children would extend the novel labels associated with pictures during referent selection to their corresponding 3-D objects.

To provide the necessary level of control when presenting stimuli, object groupings were fixed. Trials were administered in one of four possible orders per condition (evenly allocated across participants in each sample). In each order, no more than two trials of the same type (picture or object) were experienced sequentially, and the order of trials was pseudo-randomised with the constraint that the same word was never requested on consecutive trials. Positioning of objects (left, middle, right) was pseudo-randomised across trials with the constraint that the requested item did not appear in the same location more than twice consecutively.

Figure 2

Example stimuli presented at each stage of the experiment in each iconicity condition. Images with black borders represent 2-D pictures, images without black borders represent 3-D objects. The target referent is positioned on the right in the referent selection trial, in the middle on the object retention trial, and on the left in the picture retention trial



Results

Warm up trials

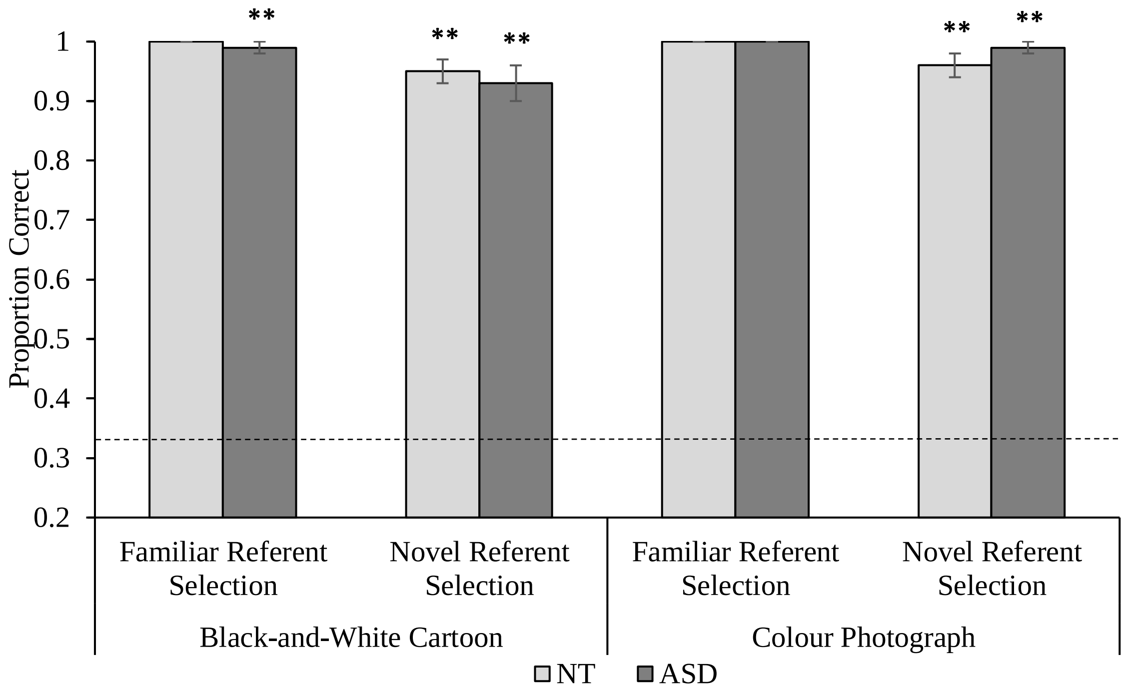
In both conditions, all participants achieved 100% accuracy in the warm-up trials.

Referent selection trials

Participants were scored out of four on familiar and novel referent selection trials (see Figure 3). These data were entered into a 2 (Population: NT, ASD) x 2 (Condition: Cartoon, Photograph) x 2 (Trial Type: Familiar, Novel) mixed ANOVA. The analysis revealed a significant main effect of Trial Type, $F(1,38) = 9.59$, MSE = 0.11, $p = .004$, $\eta_p^2 = .20$. Accuracy was significantly greater on familiar trials ($M = 3.99$) than novel trials ($M = 3.83$). The analysis also revealed a significant main effect of Condition, $F(1,38) = 4.18$, MSE = 0.07, $p = .048$, $\eta_p^2 = .10$. Children achieved significantly greater accuracy on referent selection trials in the Photograph condition ($M = 3.95$) than the Cartoon condition ($M = 3.86$). Despite these significant effects, NT children and autistic children achieved ceiling level accuracy on familiar and novel trials in both conditions (93–100%), significantly exceeding chance. No other effects or interactions were significant. Pearson’s correlations were conducted to explore relationships between referent selection and measures of individual differences. Although the populations did not differ on accuracy, it is possible that different factors contributed to their successful performance (Happé, 1995), so relationships between variables were measured for each population separately. For NT children, there was a significant correlation between accuracy on novel referent selection trials in the Photograph condition and raw score on the Leiter-3, $r(18) = .47$, $p = .04$ (see Table 2). No significant correlations were observed for autistic children.

Figure 3

Average referent selection trial accuracy for neurotypical children (NT) and autistic children (ASD) Error bars show ±1 SE. Dotted line represents chance (0.33). Stars above columns indicate where below-ceiling performance was significantly more accurate than expected by chance (** p < .001)



Retention trials

Participants were scored out of four on picture trials and out of four on object trials (see Figure 4). For picture trials, children responded correctly if they selected the picture that was assigned the requested label during the referent selection trials. For object trials, children responded correctly if they selected the object represented by the picture that was assigned the requested label during the referent selection trials. These data were entered into a 2 (Population: NT, ASD) x 2 (Condition: Cartoon, Photograph) x 2 (Trial Type: Picture, Object) mixed ANOVA. The analysis revealed no significant main effects. The Condition x Population interaction was significant, $F(1,38) = 4.57$, MSE = 1.31, $p = .039$, $\eta_p^2 = .11$, and was explored via a series of Bonferroni-adjusted pairwise comparisons. In the Cartoon condition, retention trial accuracy of NT children (*M* = 1.50) and autistic children (*M* = 1.28) did not significantly differ (*p* = .39), however, in the Photograph condition, autistic children achieved significantly greater accuracy on retention trials (*M* = 1.88) than NT children (*M* = 1.33; *t* = 2.55, *p* = .013). Whereas the accuracy of NT children did not significantly differ in the Cartoon (*M* = 1.50) and Photograph (*M* = 1.33; *p* = .47) conditions, autistic children achieved significantly greater retention accuracy in the Photograph condition (*M* = 1.88) than the Cartoon condition (*M* = 1.28; *t* = 2.20, *p* = .04). No other interactions were significant. Pearson's correlations were conducted to explore relationships between retention and measures of individual differences for each population separately. There was a significant correlation between the accuracy of autistic children on retention trials in the Cartoon condition and their raw scores on the Leiter-3, *r*(18) = .68, *p* = .001 (see Table 3). Notably, there were no significant relationships between novel referent selection accuracy and retention accuracy in either condition for either population.

Figure 4

Average retention trial accuracy for neurotypical children (NT) and autistic children (ASD). Error bars show ±1 SE. Dotted line represents chance (0.33). Stars above columns indicate where below-ceiling performance was significantly more accurate than expected by chance (p < .05)*

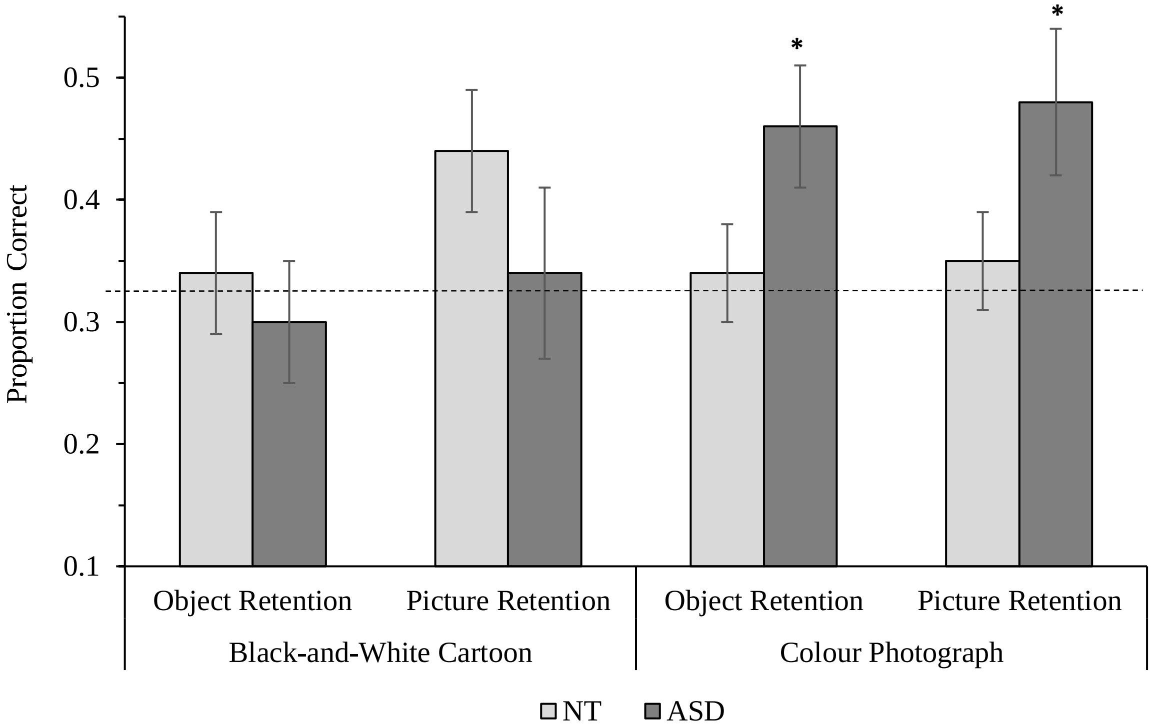


Table 2

Correlations between NT trial performance and individual difference measures (= p < .05)*

	Cartoon Ref. Sel. novel	Photo Ref. Sel. novel	Cartoon Retention Avg.	Photo Retention Avg.	Chron. age	Receptive lang.	Expressive lang.	Non-verb. raw score	Non-verb. IQ
Cartoon Ref. Sel. novel	-	.14	.08	-.05	.06	-.07	.07	.37	.10
Photo Ref. Sel. novel	-	-	0.00	-.01	-.07	.25	.07	.47*	.41
Cartoon Retention Avg.	-	-	-	-.14	.24	.40	.06	-.27	-.31
Photo Retention Avg.	-	-	-	-	.40	-.05	.25	.23	-.37

Table 3

Correlations between ASD trial performance and individual difference measures (= p <. 05)*

	Cartoon Ref. Sel. novel	Photo Ref. Sel. novel	Cartoon Retention Avg.	Photo Retention Avg.	Chron. age	Receptive lang.	Expressive lang.	Non-verb. raw score	Non-verb. IQ
Cartoon Ref. Sel. novel	-	.29	.13	.27	.21	.35	.43	.34	.21
Photo Ref. Sel. novel	-	-	.23	.42	.12	.33	.13	.27	.20
Cartoon Retention Avg.	-	-	-	-.20	.19	.34	.39	.68*	.36
Photo Retention Avg.	-	-	-	-	-.18	.02	-.20	-.20	-.04

Discussion

This study investigated how iconicity impacts the ability of autistic children and NT children to learn words from pictures. Both populations used mutual exclusivity to accurately map novel word-picture relationships in both iconicity conditions, but demonstrated substantially reduced retention accuracy. Autistic children achieved significantly greater retention accuracy in the Photograph condition than the Cartoon condition and, interestingly, responded more accurately on retention trials in the Photograph condition than NT children. Perhaps surprisingly, NT children's accuracy on picture and object retention trials did not significantly exceed chance in either iconicity condition. These findings suggest that learning words from pictures may be more cognitively challenging for NT children than learning words from objects. Our results also demonstrate that word learning in ASD is facilitated by greater iconicity, providing a data-grounded rationale for using colour photographs when administering picture-based interventions.

In referent selection trials, NT children and autistic children responded with extremely high accuracy on familiar and novel referent selection trials in both conditions. Despite a significant difference between trial types, children were almost as accurate at identifying referents of novel words (96%) and familiar words (almost 100%). This finding aligns with previous research demonstrating that children across the autism spectrum reliably use mutual exclusivity to overcome the challenge of referential ambiguity when fast mapping novel words (e.g. Preissler & Carey, 2005; de Marchena et al., 2011; Hartley et al., 2019). Similarly, despite a statistically significant effect of iconicity, differences in accuracy between conditions were also minimal (98.8% accuracy in the Photograph condition vs. 96.5% accuracy in the Cartoon condition). These data indicate that both groups of children were capable of identifying familiar referents and distinguishing them from unfamiliar referents when learning from either cartoons or photographs. Thus, iconicity had relatively little impact on children's ability to accurately fast map labels to pictures.

Despite their highly-accurate responding on referent selection trials, both populations showed substantially reduced retention accuracy after a 5-min delay. Indeed, children's referent selection accuracy did not significantly correlate with their subsequent retention accuracy, suggesting that these word learning processes are subserved by distinct mechanisms. This is broadly consistent with prior research investigating word learning from objects, where children demonstrate relatively poor retention of word meanings established through fast mapping (Hartley et al., 2019, 2020; Horst & Samuelson, 2008). However, retention accuracy for autistic children was clearly mediated by iconicity. Autistic children responded with significantly greater accuracy in the Photograph condition than in the Cartoon condition and achieved significantly greater accuracy in the Photograph condition than NT controls. The groups did not differ in accuracy in the Cartoon condition, where neither group significantly exceeded chance level accuracy on either picture or object trials. These results advance prior findings that autistic children benefit from greater iconicity when *mapping* word-picture-object relations (e.g. Hartley & Allen, 2015a) by demonstrating that they also *retain* information with greater accuracy when learning from colour photographs.

Contrary to our predictions, greater iconicity facilitated retention of newly-learned words for autistic children, but not NT children. One possibility is that our ASD sample demonstrated superior retention in the Photograph condition because they were significantly older than the NT children and may have superior phonological working memory skills (Baddeley et al., 1998). Variations in children's development of phonological working memory may influence retention of verbal information in the short-term and affect the formation of long-term representations of novel phonological material (Pierce et al., 2017; Baddeley & Hitch, 2019). However, this explanation seems unlikely as children with ASD did not achieve significantly greater retention accuracy in the Cartoon condition. An alternative, and perhaps more likely, account of our findings relates to differences in visual processing between the two populations. Autistic children reliably outperform NT controls during visual tasks with brief presentations (Plaisted et al., 1998; O'Riordan et al., 2001), and this superior performance has been attributed to enhanced perceptual processing (Mottron et al., 2006, 2013). According to this theory, neural networks underpinning perceptual processing are highly specialised in autism and elicit local, rather than global, processing of visual information. Parallels can be drawn between our surprising results and Hartley et al.'s (2019) unexpected finding that autistic children achieved significantly greater retention accuracy than NT children when tested using differently-coloured stimuli 5 min after fast mapping. Hartley and colleagues (2019) speculate that superior attention to visual features may elicit more robust encoding of word-object associations during fast mapping when exposures are brief. Therefore, it is possible that enhanced perceptual functioning afforded an advantage for autistic children when learning from more detailed representations of symbolised referents depicted in colour photographs versus less detailed black-and-white cartoons (where no advantage was observed). However, this account is speculative and warrants validation in future research.

Although greater iconicity may facilitate extension of labels from pictures to specific depicted objects for autistic children, robust symbolic understanding requires children to generalise labels to multiple category members. Indeed, this is an important objective for picture-based communication interventions. However, recent studies of neurotypical development suggest that increased iconicity may inhibit generalisation. Menendez and colleagues (2020) taught NT undergraduate students about metamorphosis in ladybirds using life-cycle diagrams that varied on iconicity. Although both perceptually 'rich' and 'bland' diagrams supported learning, the 'rich' diagrams impeded students' ability to generalise newly-acquired knowledge to other insects. The authors suggest that more iconic learning materials may restrict participants' ability to generalise because they depict a specific, concrete example of a category, compared to less iconic learning materials that could be interpreted more broadly (Sloutsky et al., 2005). These findings raise the possibility that learning via colour photographs may help autistic children to map one-to-one picture-object relationships whilst potentially impeding their understanding of pictures as representations of categories. Counter to this, Hartley and Allen (2015a) found that minimally-verbal autistic children (many of whom were recipients of picture-based interventions) generalised labels to differently-coloured objects with greater accuracy when learning from colour photographs and colour cartoons in comparison to black-and-white cartoons and greyscale photographs. Nevertheless, further research exploring the influence of iconicity on children's generalisation of word-picture relationships is required.

The lack of an iconicity effect for NT children may be due to their general tendency to preferentially encode shape when processing objects (Landau et al., 1988; Samuelson & Smith, 2000; Perry & Samuelson, 2011) and pictures (Hartley & Allen, 2014a, 2015b). As a general learning principle, shape determines what an object is and therefore the label it should receive (Smith, 2000). By approximately 24-months, NT children spontaneously extend unfamiliar labels mapped to novel objects and pictures to additional unlabelled referents based on shape, rather than other perceptual cues such as colour or texture (Landau et al., 1988). Importantly, clearly-recognisable shape cues associated with unfamiliar objects were provided in both the Photograph and Cartoon conditions. For children who primarily focus on shape when learning new object names, it is possible that the category-irrelevant perceptual details afforded by photographs (e.g. colour) do not contribute to encoding stronger word-referent associations when fast mapping (indeed, these additional cues may actually be distracting; see Horst et al., 2019).

Given that the NT group failed to achieve above-chance retention accuracy on any trial type, it may be that the challenge of retaining words learned from pictures is inherently more difficult for these children than words associated with objects. In studies that involve learning names for 3-D objects through fast mapping, it is common for NT three-year-olds to achieve above-chance accuracy (e.g. Horst & Samuelson, 2008; Horst et al., 2010). In our study, poor performance on picture retention trials is particularly surprising, as children were tested with the exact stimuli that words were mapped to during referent selection, mirroring conventional retention trials in object learning studies (e.g. Hartley et al., 2019). By 24-months, NT children understand that words paired with pictures relate to independently existing referents and accurately extend labels from pictures to objects (e.g. Ganea et al., 2008; Preissler & Carey, 2004; Hartley & Allen, 2014a, 2015a). Thus, it is likely that our NT participants realised that labels paired with pictures during referent selection actually referred to independently existing referents. Rather, children's difficulty retaining words associated with pictures could be explained by the scarcity of dimensional and tactile information afforded by 2-D representations in comparison to 3-D objects. Our data may suggest that generating a robust mental representation of an independently existing object from 2-D sensory input, that can be retrieved after a 5-min delay, could be the challenge for NT children when fast mapping from pictures. Although NT children are capable of developing mental representations of symbolised referents (Hartley & Allen, 2015b), retaining these representations could be an ability that develops with age, and could potentially lag behind retention of object representations due to scarcity of information provided at encoding.

Our findings emphasise the importance of studying word learning as a system involving fast mapping and retention mechanisms (McMurray et al., 2012). Most notably, a lack of between-population differences during mapping does not necessarily mean that no differences will be observed for retention. While the majority of previous research exploring children's learning from pictures has focused on mapping and neglected retention, our findings demonstrate a pressing need to measure *both* of these abilities in order to gain a more comprehensive account of picture-based word learning. We recommend that future studies investigating word learning in ASD should follow this approach. Given the possibility that young NT children might not be as adept at learning vocabulary from pictures compared to objects, we also suggest that future research should bear this in mind when considering methodology and the use of picture vs. object stimuli. From a practical perspective, our findings suggest that word learning in ASD is facilitated by greater iconicity, which supports the use of colour photographs when administering picture-based interventions in clinical and educational contexts.

Of course, we must reflect on the limitations of this study. Caution must be exercised when attempting to generalise our results across the autism spectrum. As language development in ASD is extremely heterogeneous, it is important to acknowledge that while mutual exclusivity based referent selection may be a strength for most of the population, the retention of word-referent relationships is likely to be extremely varied, especially when learning conditions are less favourable. Therefore, individuals with more severe developmental delay and language difficulties than those displayed by our sample may experience weaker retention. It is also important to acknowledge that the strong performance of autistic children may partly be attributed to the tightly controlled learning conditions; participants were presented with arrays of only three objects, mapping was not dependent on attention to external factors, distractions were minimised, and participants' response times were unrestricted. It is also plausible that the performance of our autistic participants may have been facilitated by prior training on picture-based communication interventions. As we did not record details concerning our participants' intervention histories, we acknowledge the possibility that the ASD group may have performed particularly well in the Photograph condition because they were familiar with communicating via photographs (although the iconicity of images employed by picture-based interventions varies markedly; Bloomberg et al., 1990; Mirenda & Locke, 1989). Moreover, accuracy is only one way to measure word learning. As we did not measure response times, it is possible that our ASD sample may have taken longer than NT participants to respond correctly. Hartley et al. (2020) recently found that autistic children achieved similar accuracy to vocabulary-matched NT controls, but took significantly more time to generate correct responses. Increased processing time could have significant implications for symbolic understanding of pictures in the real world. In more naturalistic language-learning environments, there would be considerably more noise and external distractions, and quite possibly a greater number of familiar and novel objects visible during a naming event. It is conceivable that comparing our populations under such learning conditions could yield very different results (Yurovsky et al., 2013).

In summary, our study has provided the first account of children's ability to map *and* retain novel object names when learning from pictures that vary in iconicity. Although autistic children and NT children performed accurately during fast mapping, regardless of iconicity, both populations demonstrated substantially reduced retention accuracy. However, when learning from photographs, rather than cartoons, autistic children achieved significantly greater retention accuracy and responded more accurately than NT children. Overall, this research informs understanding of word learning in ASD and identifies possible methods of supporting vocabulary acquisition when learning from pictures.

Chapter 6: General Discussion

This thesis has examined concurrent interrelationships between symbolic and social-cognitive domains in autistic and neurotypical children, and investigated how ASD influences children's ability to learn words from pictures that vary in iconicity. The ontogenetic development of symbolic understanding has been subject to considerable discussion, and has prompted the formulation of several theoretical frameworks, including Vygotskian social-cultural perspectives, Piagetian domain-general accounts, and Chomskian domain-specific theories. However, establishing which of these models best represents the interrelations between communicative domains in neurotypical and autistic children is challenging due to the limited availability and scope of previous evidence. Existing research fails to provide a comprehensive profile of children's symbolic abilities because it has predominantly focused on investigating social communication, pictures, and play in isolation, or exploring predictive relationships between only two of these symbolic domains at a time. Furthermore, many studies overlook the importance of measuring receptive and expressive abilities within each symbolic domain. This is problematic because neurotypical infants' comprehension skills usually outweigh their productive skills in every symbolic domain (Callaghan, 1999), and they may differ in terms of their interrelationships with other abilities. The empirical studies that comprise this thesis address these gaps in the research literature.

In early neurotypical development, language emerges from social communication abilities, which may then in turn provide a platform for acquiring skills in non-linguistic symbolic domains (Kirkham et al., 2013; Vygotsky, 1978). If this is the case, then diagnosis-defining differences in social communication in ASD could have significant repercussions for symbolic understanding, and prompt alternative routes for learning in this population. For example, if autistic individuals develop play and pictorial understanding despite experiencing significant challenges in language and social communication, then this would imply more independent functioning of these non-linguistic symbolic domains in autism. Understanding how symbolic abilities are influenced by individual differences, as well as examining the interrelatedness of communicative domains, could also inform the design and implementation of educational and clinical interventions. Therefore, Studies 1 and 2 modelled predictive relationships between pictorial, play, and social communication domains, alongside individual differences such as language abilities, non-verbal intelligence, and fine motor skills, in neurotypical and autistic children respectively. Study 3 compared predictive relationships between symbolic domains in language-matched autistic and neurotypical participants.

In Study 1, neurotypical 2–5-year-olds completed a battery of standardised assessments and experimental tasks. Based on previous evidence (e.g. Callaghan & Rankin, 2002; Hartley et al., 2019; Kirkham et al., 2013), we anticipated that we would find positive predictive relationships between social communication, pictures, and play. Identifying that social communication predicts pictures and play (but not the reverse) would support social-cultural perspectives (Vygotksy, 1978), while bidirectional relationships between the three modules would align more closely with domain-general accounts of symbolic understanding (Piaget, 1952).

In line with previous studies, we found that more advanced expressive and receptive language abilities predicted more sophisticated symbolic play (Callaghan & Rankin, 2002; Kirkham et al., 2013). Reciprocal relationships were identified between social communication and play, social communication and pictures, and pictures and play. This pattern of positive concurrent interrelationships (visualised in Figure 1) suggests that these modules are interdependent and potentially underpinned by common underlying factors, such as the achievement of representational insight (DeLoache, 1995; Pleyer, 2020). This ability to realise the symbolic relationship between a symbol and its referent is a complicated process that unravels gradually during the first few years of life. Attaining representational insight is dependent on the interaction of numerous factors, including the degree of iconicity between symbol and referent, the level of information provided about the symbol-referent relationship, and the extent of prior symbolic experience (DeLoache, 2000). Levels of understanding can vary from an implicit and fragile awareness of symbolic relations to more explicit and secure mental representations of relations, akin to mature adult abilities (Zelazo & Frye, 1997). For instance, neurotypical children begin to use words to request and identify specific things in the environment around their first birthday (Tager-Flusberg et al., 2009; Zubrick et al., 2007) engage in pretend play using objects 'as if' they were something else at around 18-months-old (Bergen, 2002; Lillard, 2017; McCune, 1995), and use and produce pictures referentially around the age of 3 years (Callaghan, 1999; Jolley & Rose, 2008; Nelson, 2007). Thus, the neurotypical participants in Study 1 (*M* age = 42.66 months) are likely to have had a robust, rather than fragile, understanding of symbolic representations, enabling successful interpretation and manipulation of symbols across various domains.

The findings of Study 1 are consistent with previous research demonstrating that 3–4-year-olds' linguistic, pictorial, and play skills are interrelated and develop in parallel during this specific timepoint (Kirkham et al., 2013), as well as prior research identifying significant positive correlations between pictures and play, pictures and language, and play and language (Callaghan & Rankin, 2002). Overall, our findings most closely align with a domain-general account of symbolic functioning in neurotypical children (Piaget, 1952), whereby social communication, play, and pictorial domains develop in relative synchrony. These concurrent interrelations between domains could potentially be underpinned by specific cognitive mechanisms that promote referential awareness (i.e. being aware that *something* can be referred to) and support joint attention, alongside other fundamental skills such as vocal/motor control and visual memory (McCune, 2008). Being aware that attention on some external thing is shared and understanding the significance of such intersubjectivity for communication facilitates language acquisition (Baldwin, 1995; Bruner, 1983; Carpenter et al., 1998; Morales et al., 1998; Mundy & Gomes, 1998; Tomasello, 2003a), and might also support children's use and understanding of pictures and symbolic play acquired during social interactions with others (Baldwin, 1995). As sophistication of play and pictorial understanding develops, children's general awareness and sensitivity to others as communicative agents who can act referentially and receive referential communication might also improve.

In Study 2, autistic 4–11-year-olds completed the same battery of standardised assessments and experimental tasks as neurotypical participants in Study 1. Considering the well-documented challenges associated with ASD – affecting acquisition of social communication (Werner et al., 2000; Wetherby et al., 2004), language (Tager-Flusberg & Kasari, 2013), pictures (Hartley & Allen, 2015; Preissler, 2008), and play (Hobson et al. 2013; Jarrold, 2003) – we predicted that symbolic understanding could potentially be interconnected or independent across domains. Stanley and Konstantareas (2007) provide evidence of interconnectedness between social communication, language, and symbolic play in autistic children, suggesting that delays and differences in one area may influence performance outcomes in other domains. Thus, symbolic understanding of play and pictures may be acquired via the same route as in neurotypical development, with language and/or social communication mediating early acquisition of non-linguistic symbolic domains (Anderson et al., 2007; Vygotsky, 1978). If symbolic modules operate interdependently, more developed social communication skills would likely predict more sophisticated understanding of play and/or pictorial domains. Alternatively, due to linguistic and social-cognitive differences in ASD play and pictorial abilities could develop independently, and a child could potentially have sophisticated play and/or pictorial abilities in conjunction with relatively underdeveloped language (Mundy, 1995). If this is the case, then an absence of predictive relationships between domains would be found, providing support for domain-specific accounts.

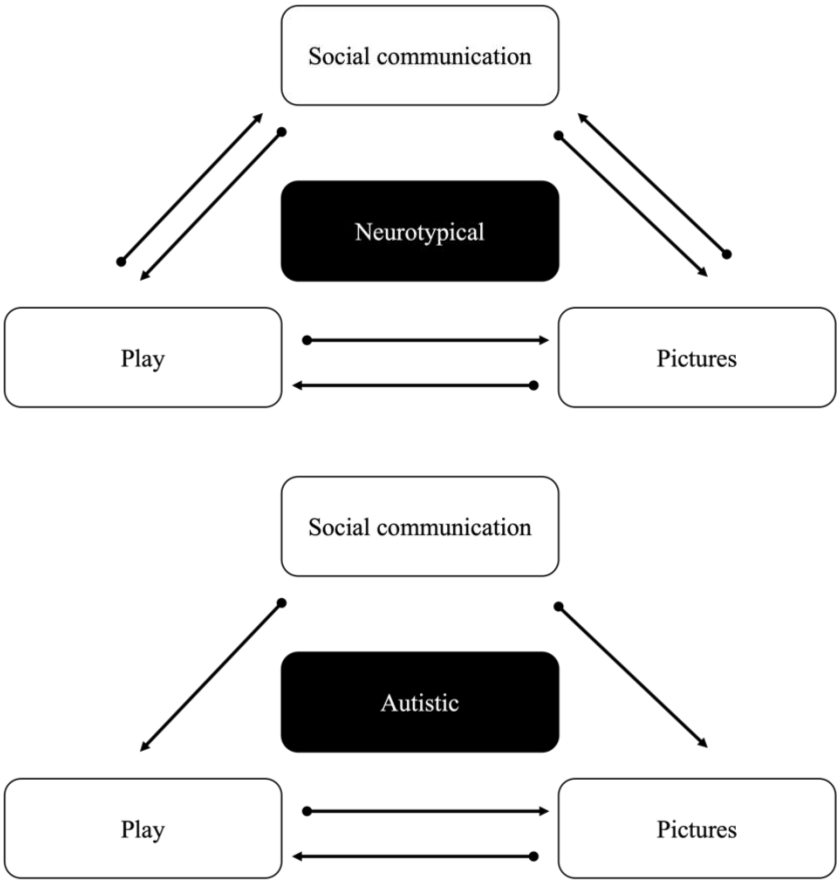
We found that better social communication abilities predicted more advanced symbolic play and pictorial skills in autistic children, and a bidirectional relationship between pictures and play was detected. These findings, which are visualised in Figure 1, provide evidence of interconnectedness between various communicative domains in this sample, and suggest that delays and/or differences in social communication may influence understanding in the symbolic domains of play and pictures. As our picture comprehension task specifically manipulated the availability of linguistic scaffolding, an effect of trial type suggests that some autistic participants utilised linguistic scaffolding to correctly identify depicted target objects. This is consistent with previous research (e.g. Hartley et al., 2019), and could indicate that children who have more severe delays in vocabulary development might also struggle with matching pictures to symbolised referents. Our findings are broadly consistent with other research identifying concurrent relationships between language and symbolic play, and social communication and symbolic play (Stanley & Konstantareas, 2007). However, our study advances prior research by revealing interrelationships with pictorial domains. The bidirectional relationship evidenced in our data corroborates previous research identifying reciprocity between pictures and symbolic play in neurotypical children (Kirkham et al., 2013; Carter & Hartley, in prep a, see Chapter 2). As for neurotypical children, pictures and play both require the capacity for symbolic understanding, so it is possible that representational insight may serve as a shared mechanism underlying both domains in autistic children too (Pleyer, 2020).

However, unlike in Study 1, proficiency in play and pictorial domains did not appear to be reciprocally related to autistic children's social communication abilities. This absence of bidirectional relationships suggests that while social communication abilities and/or scaffolding might aid autistic children's understanding of both symbolic play and pictorial skills, more advanced understanding of play and pictures does not increase social communication aptitude in return. This implies that autistic children who experience more severe social challenges may potentially demonstrate more pronounced challenges with symbolic understanding across play and pictorial domains, and that more advanced understanding within these domains does not necessarily mean that children have better social skills. Considering the diagnosis-defining differences in social-cognition and social-motivation in ASD (American Psychiatric Association, 2013), this phenomenon may arise from autistic children perceiving social cues as less salient than physical stimuli, leading to a selective focus on the latter. Consequently, this selective attention may foster a predisposition towards specialised understanding and interaction with objects rather than with people (Klin et al., 2003), leading to advances in play and pictorial understanding. In our autistic sample, it is possible that more socially oriented individuals spent more time engaged in situations involving play and pictures, facilitating advancement in these non-linguistic domains, without affording reciprocal advances in social communication.

Overall, the findings of Study 2 are consistent with Vygotskian social-cultural theories, suggesting that autistic children's social communication skills provide a scaffolding base for other symbolic domains. Notably, the interrelations we identified closely resemble those that might be expected in younger neurotypical children aged ~1–2 years (Anderson et al., 2007; Vygotsky, 1978), although not in our slightly older NT sample in Study 1. Although the receptive language abilities of children in Study 1 and Study 2 were comparable (ASD: *M* age = 44.11 months; NT: *M* age = 45.12 months), it is possible that other capacities relevant to symbolic understanding (e.g. referential awareness and representational insight) were more advanced and robust in the neurotypical children compared to the autistic children (Perner, 1991; Zelazo & Frye, 1997).

Figure 1

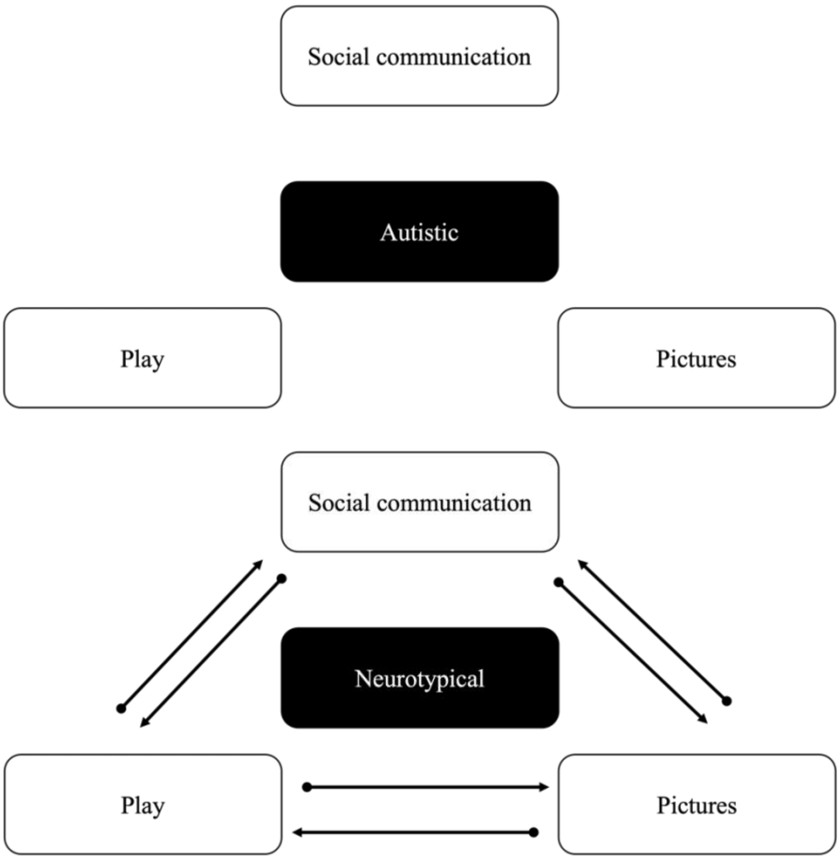
Visualisation of the relationships between symbolic domains in Studies 1 and 2



Note. Arrows represent direction of predictive effects

Study 3 explored potential differences between predictive relationships across symbolic domains and demographic characteristics in neurotypical and autistic children matched on language comprehension abilities. These population comparisons allowed for the detection of differences in the presence, strength, and magnitude of inter-domain relationships between the two groups of children. Our analyses revealed a matrix of bidirectional relationships between pictures, play, and social communication in neurotypical children, indicating that relationships between these domains are much stronger than in ASD. In contrast, the comparatively weaker concurrent interrelationships observed in autistic children indicate that domains are relatively more independent in this population. So, although Study 2 provides evidence of relationships between some domains in autism, Study 3 demonstrates clear differences in the nature and strength of these relationships in comparison to neurotypical children with equivalent language abilities (see Figure 2). While the interconnectedness of domains identified in neurotypical children provides support for domain-general accounts, the relative independence observed in autistic children is more closely aligned with domain-specific accounts of symbolic understanding.

Figure 2. Visualisation of the relationships between symbolic domains in Study 3



Note. Arrows represent direction of predictive effects

Our findings challenge the notion that a single theoretical model can fully explain the development of symbolic abilities in both neurotypical and autistic children. Instead, they suggest that different models may be more applicable depending on the developmental stage or specific abilities being assessed. For example, in early neurotypical development, when representational insight is fragile, a sociocultural account may be most relevant, with caregivers and peers playing a central role in shaping symbolic abilities (Vygotsky, 1978). As children mature and their representational skills become more established, development may shift toward a domain-general model. Here, cognitive abilities across various domains – such as motor, language, and visual skills – could become more integrated, with symbolic understanding potentially being influenced by broader cognitive processes that transcend specific social contexts. This reflects the idea that early socially scaffolded abilities might evolve into a more comprehensive cognitive framework. This perspective aligns with dynamic systems theory, which posits that development is nonlinear and characterised by periods of stability and change, with various systems interacting in complex ways (Smith & Thelen, 2003). According to this theory, the evolving interplay between motor skills, language, and symbolic understanding shifts as children progress through developmental stages could make certain theoretical accounts more relevant at different times.

This idea can also be extended to understanding variability in autistic children, who exhibit a wide range of abilities and developmental trajectories. For some autistic children, a domain-specific model may initially be more applicable, with symbolic development closely tied to specific cognitive systems, such as motor skills or visual processing. As development progresses, reliance on these specific domains may shift towards more integrated processes. For instance, autistic individuals who start with domain-specific routes to symbolic understanding may later transition to domain-general mechanisms, where cognitive and symbolic abilities become co-ordinated across multiple systems. Conversely, for autistic children with stronger social communication skills, a sociocultural model that emphasises the role of social interaction in cognitive development may be more relevant (Vygotsky, 1978). As these children's symbolic understanding becomes more sophisticated, the relevance of domain-specific models might diminish in favour of more integrative approaches that encompass social, cognitive, and symbolic development.

This variability in the applicability of different theoretical models underscores the importance of considering individual differences, particularly within the autistic population. The phenotypic diversity observed in autism suggests that no single model can account for all aspects of development across individuals. Instead, different levels of difficulty in the domains of motor skills, language, and symbolic play might relate to the specific phenotype that a particular autistic individual demonstrates. For example, the symbolic development of an autistic child with notable fine motor difficulties might be most accurately understood through a domain-specific model that emphasises the role of motor skills in cognitive development. Conversely, a child with more significant social communication challenges might be better understood through a sociocultural perspective, which highlights the importance of social interaction in cognitive growth.

Recognising that different theoretical models may hold varying degrees of relevance at different stages of development has important implications for future research. Developmental studies should aim to capture these changes over time, perhaps by focusing on discrete age groups or by longitudinally tracking changes in symbolic abilities. Such approaches would help identify which theoretical account(s) best explain development at each stage. Moreover, this perspective invites a more integrative approach to developmental theory, one that recognises the contributions of multiple models rather than forcing a choice between them. By considering that different models might apply at different times or in different contexts, we can develop a more comprehensive understanding of how children –

both neurotypical and autistic – navigate the complexities of symbolic development.

Collectively, Studies 1, 2, and 3 address several important gaps in the literature to provide a comprehensive account of concurrent interconnectedness between social communication, play, and pictures in neurotypical and autistic populations. Although the measures of picture comprehension and production in studies 1–3 indicate general aptitude, it is possible that performance related to these abilities might differ if tested via alternative tasks. Furthermore, variability in environmental factors and stimuli (e.g. iconicity) might influence children's pictorial understanding, and relations with other skills/domains might alter as situations change. Therefore, Study 4 provides a more detailed investigation into a different aspect of picture comprehension – learning and extending new vocabulary from pictures of unfamiliar objects – and how this varies across different kinds of pictures. While Studies 1–3 assess children's basic picture-object matching abilities, Study 4 provides the first account of fast mapping and retention abilities, in both autistic and neurotypical children, when learning novel words from pictorial stimuli varying in iconicity.

Understanding how vocabulary is learned from pictures is particularly important due to its practical implications, especially in education and interventions where visual supports play a crucial role in aiding communication, comprehension, and retention of information. Furthermore, physical and digital AAC interventions for autistic children predominantly use pictures to teach functional communication skills and encourage labelling using physical, tangible symbols (e.g. PECS; Bondy & Frost, 1994) and digital interactive systems (e.g. Proloquo2Go; Sennott & Bowker, 2009). However, the lack of data-grounded guidelines regarding which types of pictorial symbols to use in these systems has resulted in considerable variability in the iconicity of visual supports provided across different contexts. Iconicity refers to the degree of resemblance between a symbol and its corresponding referent, and research shows that it can significantly impact children's understanding of symbolic word-picture-object relationships (Ganea et al., 2008; Keates et al., 2014; Simcock & DeLoache, 2006). Highly iconic pictures closely resembling their referents, such as colour photographs, are easier to recognise and comprehend compared to less iconic pictures, such as black-and-white line drawings, which bear less resemblance to their referents. When there is greater perceptual similarity between a picture and its referent, the salience of the underlying symbolic relationship may be more apparent, thereby increasing the likelihood of the viewer identifying and understanding the connection (DeLoache, 1995). By identifying which types of pictures facilitate better vocabulary learning outcomes, interventions can be tailored to utilise more effective visual aids for both neurotypical and autistic children.

To determine whether language-matched autistic and neurotypical children would retain object names more accurately when learning from colour photographs or black-and-white cartoons, participants identified the meanings of novel words in a standard referent selection task. Our results demonstrate that both groups achieved high accuracy rates in both familiar and novel referent selection trials, regardless of iconicity. However, both populations showed substantially reduced retention accuracy after a 5-min delay. The absence of a relationship between children's referent selection accuracy and subsequent retention accuracy suggests that these word learning processes may be subserved by distinct mechanisms. This broadly aligns with previous research investigating children's word learning from objects, which demonstrates limited retention of word meanings established through fast mapping in both autistic and neurotypical children (Hartley et al., 2019; Horst & Samuelson, 2008).

While iconicity had relatively little impact on children's ability to accurately fast map labels to pictures, our findings reveal variability in retention accuracy among autistic children, depending on the iconicity of the presented stimuli. Autistic children achieved significantly greater accuracy when learning from colour photographs compared to black-and-white cartoons and, surprisingly, demonstrated more accurate performance than NT children when learning from photographs. These findings suggest that learning words from pictures may present a greater cognitive challenge for neurotypical children compared to learning from objects. However, autistic children may derive greater benefit from increased iconicity when learning words from pictures. This supports and expands upon earlier findings that increased iconicity facilitates accurate mapping of word-picture-object relations in ASD (e.g. Hartley & Allen, 2015a), by demonstrating that autistic children also exhibit enhanced retention accuracy when learning from colour photographs. This underscores the importance of optimising the environment to aid children's learning and provides a data-grounded rationale for using colour photographs when implementing picture-based AAC interventions. Furthermore, it also raises an important broader issue for researchers, suggesting that participants' data, as well as researchers' conclusions regarding picture comprehension, may be influenced by variations in experimental tasks and stimuli.

The findings from Study 4, which included a subset of participants who were involved in studies 1 and 2, contribute to broader understanding established in the preceding three studies by providing additional insights into the relationship between language and picture comprehension in autistic and neurotypical children. Study 3 revealed that despite being matched on language, autistic children scored significantly lower on all social communication measures compared to language matched NT participants. Despite these differences in low-level social skills, autistic participants in Study 4 exhibited ceiling-level accuracy in referent selection trials, indicating that their baseline social communication difficulties did not hinder their ability to map and retain novel-word referent associations learned from pictures. This indicates a good understanding of symbolic word-picture-object relationships in spite of relatively lower social communication skills, suggesting relative independence of domains (as observed in Study 3).

The inter-domain relationships identified in this thesis could have important implications for pedagogy, suggesting that specific tasks or developmental activities may yield broader benefits across multiple domains, rather than solely targeting one area. This developmental theory underpins Naturalistic Developmental Behavioural Interventions (NDBI) – a type of intervention that prioritises improving the synchrony, reciprocity, and duration of children's social interactions to address delays and differences in social communication, thereby fostering cascading improvements in developmentally related skills. For example, an NDBI – Joint Attention, Symbolic Play, Engagement, and Regulation (JASPER) – that specifically targets autistic children's social communication and symbolic play skills has been shown to improve both IJA and RJA, enhance symbolic play skills, and predict more developed productive language abilities one year post-intervention (JASPER; Kasari et al., 2006, 2008). Randomised controlled trials indicate that relationship-based interventions delivered by therapists and educators are beneficial and effective for supporting symbolic development in autistic toddlers (Dawson et al., 2010; Landa et al., 2011). These therapeutic approaches focus on building relationships between the child and their caregivers or therapists, employing strategies to enhance joint attention, shared engagement, and communication reciprocity, which can positively impact language development, symbolic play, and the understanding of pictorial symbols (Sandbank et al., 2019). Thus, the inter-domain relationships identified in this thesis could also be exploited by clinical and educational interventions aimed at facilitating symbolic development in ASD. For instance, children experiencing difficulties in one symbolic domain, such as drawing, could benefit from play-based interventions that specifically focus on their receptive and expressive abilities in other related modules, such as social communication and play.

It is important to acknowledge the limitations of our studies. Unfortunately, due to the COVID-19 pandemic, educational settings and research facilities closed, which meant it was not possible to re-test participants 12 months after their initial assessment as originally planned. Consequently, although our data indicate how variables interrelate with each other at the time of testing, we are unable to draw any causal, developmental conclusions. Additionally, pinpointing the specific ages at which these relationships emerge and evolve is challenging since we did not analyse discrete age groups. Hence, we recommend that future studies utilise longitudinal designs to address remaining gaps in the literature (Russ & Wallace, 2013), particularly in establishing causal relationships between infants' early acquisition and subsequent development of pictorial, play, and social communication domains. Moreover, longitudinal studies would also provide important evidence regarding the developmental interrelationships between these symbolic domains (e.g. Kirkham et al., 2013), which could be used to support symbolic development in both neurotypical and neurodiverse populations. Since we did not document participants' use of AAC and exposure to interventions, we were unable to assess the influence of these extraneous variables. We would therefore recommend that future studies obtain this information to better understand its impact.

Considering the heterogeneity of ASD, our findings may primarily reflect specific demographic characteristics, such as delayed language development or intellectual disabilities. These limitations potentially restrict the generalisability of our results across the autism spectrum, emphasising the importance of recruiting larger and more diverse samples in future studies. The wide variability in cognitive abilities, sensory preferences, and behavioural patterns often necessitates individualised approaches in research. This diversity complicates the design of standardised tests, demanding additional time, resources, and flexibility in study designs (Russell et al., 2019). Therefore, researchers must develop inclusive and adaptable methodologies to ensure accurate representation across the entire spectrum and improve generalisability.

Conducting research with autistic children presents several unique challenges that impact both the research process and data quality. Communication is a primary issue, as many autistic children have limited verbal skills or are non-verbal, complicating instruction delivery and response collection (Anderson et al., 2007; Norrelgen et al., 2015). Traditional testing methods may not be suitable, often necessitating alternative communication methods such as PECS or AAC devices. Additionally, the complexity of instructions or multi-step tasks may overwhelm some children, making it difficult for them to follow along (Lord et al., 2018). Another challenge is accurately assessing receptive and expressive language, as limited verbal skills may prevent traditional methods from capturing the full range of a child's communication abilities (Kwok et al., 2015).

In addition to communication difficulties, sensory sensitivities also pose significant challenges. Autistic children may have heightened sensitivity to stimuli such as lights, sounds, or textures, which can lead to anxiety or difficulty focusing during assessments (Ben-Sasson et al., 2009; Tomchek & Dunn, 2007). Researchers may need to mitigate sensory triggers by adjusting the environment, for example, using noise-cancelling headphones or sensory aids like fidget toys. Similarly, behavioural challenges further affect the research process. Issues with transitions, changes in routine, or non-cooperation may arise, and repetitive behaviours or restricted interests can distract children from tasks (Schneider & Goldstein, 2010). Limited attention spans can reduce focus if tasks are not engaging. To address these issues, researchers may need to tailor tasks to the child's interests.

Recruitment of autistic participants also presents significant challenges. Families may hesitate to involve their children due to the demands of the diagnostic process, communication difficulties, sensory sensitivities, or behaviour management issues. Schools, which are often key venues for participant recruitment, may lack the resources to support one-to-one testing (Fletcher-Watson et al., 2019). These barriers can result in self-selecting samples that may not fully represent the autism spectrum, thus reducing generalisability (Russell et al., 2019). Self-selection may also affect the interpretation of findings. For example, in studies examining fine motor skills, there may be an overrepresentation of children with milder difficulties, skewing conclusions about the relationship between these skills and broader developmental domains (Gonzalez et al., 2019). Therefore, future studies should employ more inclusive recruitment strategies and flexible designs to accommodate a wide range of abilities. Incorporating various communication methods and providing additional support for participants where necessary will also be crucial to improving the diversity and representativeness of samples (Fletcher-Watson et al., 2019).

In summary, this thesis has addressed significant gaps in the existing research literature through four empirical studies. It provides a detailed and thorough account of simultaneous predictive relationships between multiple symbolic domains in autistic and neurotypical children. Furthermore, it presents novel insights into these children's capacity to map *and* retain novel object names when learning from pictures with varying levels of iconicity. Overall, this body of research contributes to a deeper and more nuanced conceptual understanding of symbolic abilities in both neurotypical and autistic populations, providing important insights that inform the ongoing debates in the field concerning theoretical models of symbolic development. Moreover, the findings have practical implications for the development and implementation of clinical and educational interventions designed to support children's developing pictorial, play, and social-communicative abilities. The research presents important considerations for optimising picture-based AAC systems to ensure that they effectively support and enhance communication for autistic individuals. This underscores the importance of conducting further research in this area and incorporating empirical findings into AAC design to better support and serve the unique needs of autistic individuals.

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Appendix A. Adapted scoring system for symbolic play and social communication tasks

INDEPENDENT FREE PLAY

Toy/object	**Spontaneous pretend play**	**Functional play**	**Limited, repetitive play OR no play with toys**
pop-up toy			
nesting cups			
2 animals			
book			
toy telephone			
pieces of yarn			
gold lid			
baby doll			
8 letter blocks			
2 balls			
2 identical cars			
4 small plastic utensils			
4 small plastic plates			
cup			

Unusual sensory interest in play materials	**Y** [1]		**N** [0]
Adult intervention/modelling required	**Y** [1]		**N** [0]
Imitates modelled pretend play	**Y** [1]	**N/A** [0]	**N** [0]

<u>BIRTHDAY PARTY</u>

Puts candles on cake	**Y** [1]	**N** [0]
Sings Happy Birthday	**Y** [1]	**N** [0]

Blowing out candles

Helps baby to blow out candles [use of doll as independent agent]	Blows out candles but does not help baby to do so [does not use doll as independent agent]	Imitates blowing out candles after explicit demonstration	Does not blow out candles
[3]	[2]	[1]	[0]

Feeding baby

Feeds baby immediately in response to 1st prompt	Feeds baby after 2nd prompt	Feeds baby after explicit demonstration	Does not feed baby
[3]	[2]	[1]	[0]

Giving baby a drink	**Y** [1]	**N** [0]

Cleaning up

Immediately pretends to clean up the spillage in response to 1st prompt	Pretends to clean up the spillage in response to 2nd prompt	Pretends to clean up the spillage after E provides a napkin	Does not clean up
[3]	[2]	[1]	[0]

Putting baby to bed

Immediately covers baby with blanket in response to 1st prompt	Covers baby with blanket after 2nd prompt	Puts baby to sleep after E provides blanket	Does not put baby to bed
[3]	[2]	[1]	[0]

Appendix B. Adapted scoring system for social communication tasks

SOCIAL COMMUNICATION SKILLS

Response to name

Makes eye contact with E after 1^{st} or 2^{nd} press	Makes eye contact with E after 3^{rd} or 4^{th} press	Does not make eye contact, but shifts gaze briefly OR looks towards interesting vocalisation	NEVER looks towards E after any vocal attempt to acquire attention
[3]	[2]	[1]	[0]

Response to Joint Attention

Follows E's GAZE toward referent	Follows E's POINT towards referent	Looks at referent when activated	Does not look at referent
[3]	[2]	[1]	[0]

Responsive Social Smile

Smiles immediately in response to 1^{st} or 2^{nd} smile by E	*Partially* smiles after 1^{st} or 2^{nd} smile	Smiles in response to physical contact	NEVER smiles in response to E
[3]	[2]	[1]	[0]

Unusual eye contact

	Y	**N**
	[0]	[1]

Giving (SPONTANEOUS)

Gives items to others (including pretend play)	Rarely/never gives items to others
[1]	[0]

SPONTANEOUS Initiation of Joint Attention

ONE clear attempt to direct E's attention to <u>*distal*</u> referent (MUST inc. 3 point gaze shift)	Indicates a distal referent, but does not look at E OR look back at referent	No attempts to direct attention towards a distal referent
[2]	[1]	[0]

Appendix C. Model building sequences for results reported in the main text

Study 1: Examining Individual Differences Within Domains, NT Only

Picture Comprehension

We began with a baseline model containing by-participant and by-item random intercepts. Fixed effects of Trial Type (Model 2), Trial Number (Model 3), Chronological Age (Model 4), Receptive Language (Model 5), Expressive Language (Model 6), Fine Motor Skills (Model 7), and Non-verbal Intelligence (Model 8) were entered individually. The individual addition of Fine Motor Skills (χ^2 = 5.18, p = .023) and Non-verbal Intelligence (χ^2 = 5.93, p = .015) yielded significant improvements in fit when compared with the baseline model. The addition of Trial Type (p = .079), Trial Number (p = .302), Chronological Age (p = .278), Receptive Language (p = .386), and Expressive Language (p = .577) did not improve fit.

Model 9 included both of the fixed effects that individually improved predictive fit in comparison to the baseline model: Fine Motor Skills and Non-verbal Intelligence. Including these fixed effects in Model 9 did not significantly improve fit in comparison to Model 7 (p = .064) or Model 8 (p = .102).

The model containing only Non-verbal Intelligence as a fixed effect was taken as the final model as its AIC (248.2) value was lower than the model containing only Fine Motor Skills (AIC = 248.9) as a fixed effect. However, it is noteworthy that Non-verbal Intelligence and Fine Motor Skills were significantly correlated (R = 0.35, p = .024), suggesting that both variables could potentially influence Picture Comprehension. Thus, Model 8 provides the best fit to our observed data.

Picture Production

We began with a baseline model containing by-participant and by-item random intercepts. Fixed effects of Trial Type (Model 2), Trial Number (Model 3), Chronological Age (Model 4), Receptive Language (Model 5), Expressive Language (Model 6), Fine Motor Skills (Model 7), and Non-verbal Intelligence (Model 8) were entered individually. The individual addition of Trial Type ($\chi^2 = 5.69$, $p = .017$), Chronological Age ($\chi^2 = 25.46$, $p < .001$), Receptive Language ($\chi^2 = 13.60$, $p < .001$), Expressive Language ($\chi^2 = 23.50$, $p < .001$), and Fine Motor Skills ($\chi^2 = 42.31$, $p < .001$) yielded significant improvements in fit when compared with the baseline model. The addition of Trial Number ($p = .311$) and Non-verbal Intelligence ($p = .170$) did not improve fit.

Model 9 included all of the fixed effects that individually improved predictive fit in comparison to the baseline model: Trial Type, Chronological Age, Receptive Language, Expressive Language, and Fine Motor Skills. The collective addition of these five fixed effects significantly improved fit in comparison to Model 2 ($\chi^2 = 48.13$, $p < .001$), Model 4 ($\chi^2 = 28.36$, $p < .001$), and Model 5 ($\chi^2 = 40.22$, $p < .001$), Model 6 ($\chi^2 = 30.32$, $p < .001$), and Model 7 ($\chi^2 = 11.52$, $p = .021$). Therefore Model 9 is the current best fitting model.

To establish the most parsimonious model predicting children’s picture production, Models 10–14 individually removed each of the significant fixed effects that improved predictive fit to identify whether any effects are dispensable. The removal of Trial Type (Model 10; $\chi^2 = 5.25$, $p = .022$), Chronological Age (Model 11; $\chi^2 = 4.16$, $p = .042$), and Fine Motor Skills (Model 14; $\chi^2 = 16.18$, $p < .001$) yielded significant reductions in fit in comparison to Model 9. The removal of Receptive Language (Model 12; $p = .815$) and Expressive Language (Model 13; $p = .506$) did not reduce fit. As Models 12 and 13 contained fewer fixed effects but did not differ in the amount of variability predicted, these models are the current best fitting.

Model 15 omitted Receptive Language and Expressive Language, and only included Trial Type, Chronological Age, and Fine Motor Skills as fixed effects. This did not differ from Model 9 (p = .783), Model 12, (p = .510), or Model 13 (p = .828).

To confirm the predictive value of the remaining three fixed effects, each one was individually removed in Models 16-18. The removal of Trial Type (Model 16; χ^2 = 5.25, p = .022), Chronological Age (Model 17; χ^2 = 5.69, p = .017), and Fine Motor Skills (Model 18; χ^2 = 22.32, p < .001) yielded significant reductions in fit in comparison to Model 15. Thus, Model 15 provides the best fit to our observed data.

Free Play

Total Toys. We began with a model containing Total Toys as the dependent variable with five predictive effects: Chronological Age, Receptive Language, Expressive Language, Fine Motor Skills, and Non-verbal Intelligence. Non-verbal Intelligence (t = 2.24, p = .032) was statistically significant. Chronological Age (p = .912), Receptive Language (p = .562), Expressive Language (p = .839), and Fine Motor Skills (p = .245) were not significant.

Model 2 contained Total Toys as the dependent variable with the only significant predictor: Non-verbal Intelligence. Omitting the four non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (p = .374), indicating that it is the current best-fitting model.

Model 3 contained seven predictive effects: Non-verbal Intelligence, Highest Level of Play, Uses Toys as Agents, Object Substitution, Unusual Sensory Interest, Adult Intervention Required, and Imitates Modelled Play. Predictive effects of Non-verbal Intelligence (t = 2.45, p = .020), and Object Substitution (t = 2.30, p = .028) were significant. Predictive effects of

Highest Level of Play (p = .946), Uses Toys as Agents (p = .391), Object Substitution (p = .028), Unusual Sensory Interest (p = .793), Adult Intervention Required (p = .577), and Imitates Modelled Play (p = .560) were not significant.

Model 4 contained the two significant fixed effects: Non-verbal Intelligence and Object Substitution. Omitting the non-significant effects in Model 3 did not significantly reduce fit (p = .506). Therefore, Total Toys was best predicted by Model 4, $F(2, 38) = 20.90$, $p < .001$, adjusted $R^2 = 0.50$. Non-verbal Intelligence (β = 0.11 p = .008) and Object Substitution (β = 2.27, p <.001) were both significant predictors.

Highest Level of Play. In Model 1, Chronological Age (p = .978), Receptive Language (p = .655), Expressive Language (p = .833), Fine Motor Skills (p = .710), and Non-verbal Intelligence (p = .732) were not significant.

In Model 2, predictive effects of Uses Toys as Agents (t = 3.27, p = .002) and Object Substitution (t = 3.98, p < .001) were significant. Predictive effects of Total Toys (p = .723), Unusual Sensory Interest (p = .662), Adult Intervention Required (p = .239), and Imitates Modelled Play (p = .123) were not significant.

Model 3 contained the two significant predictors: Toys as Agents and Object Substitution. Omitting the non-significant predictors in Model 2 did not significantly reduce fit (p = .500). Therefore, Highest Level of Play was best predicted by Model 3, $F(2, 38) = 59.67$, $p < .001$, adjusted $R^2 = 0.75$. Toys as Agents (β = 0.45 p < .001), and Uses Toys as Agents (β = 0.45 p < .001) were significant predictors.

Uses Toys as Agents. In Model 1, Chronological Age (p = .874), Receptive Language (p = .750), Expressive Language (p = .677), Fine Motor Skills (p = .476), and Non-verbal Intelligence (p = .478) were not significant.

In Model 2, predictive effects of Highest Level of Play (t = 3.27, p = .002), Object Substitution (t = 2.60, p = .014), and Adult Intervention Required (t = 2.98, p = .005) were significant. Predictive effects of Total Toys (*p* = .104), Unusual Sensory Interest (*p* = .744), and Imitates Modelled Play (*p* = .468) were not significant.

Model 3 contained the three significant fixed predictors: Highest Level of Play, Object Substitution, and Adult Intervention Required. Omitting the non-significant predictors in Model 2 did not significantly reduce fit (*p* = .343). Therefore, Toys as Agents was best predicted by Model 3, $F(3, 37) = 27.39$, $p < .001$, adjusted $R^2 = 0.66$. Highest Level of Play ($\beta = 0.71$, $p < .001$), Object Substitution ($\beta = -0.31$, $p = .034$), and Adult Intervention Required ($\beta = -0.49$, $p = .001$) were significant predictors.

Object Substitution. In Model 1, Chronological Age (*p* = .402), Receptive Language (*p* = .435), Expressive Language (*p* = .820), Fine Motor Skills (*p* = .503), and Non-verbal Intelligence (*p* = .378) were not significant.

In Model 2, Total Toys ($t = 2.83$, $p = .008$), Highest Level of Play ($t = 3.98$, $p < .001$), and Uses Toys as Agents ($t = 2.60$, $p = .014$) were significant predictors. Predictive effects of Unusual Sensory Interest (*p* = .854), Adult Intervention Required (*p* = .196), and Imitates Modelled Play (*p* = .795) were not significant predictors.

Model 3 contained the three significant fixed effects: Total Toys, Highest Level of Play, and Uses Toys as Agents. Omitting the non-significant predictors in Model 2 did not significantly reduce fit in comparison to Model 2 (*p* = .214).

Models 4-6 individually removed each of the three fixed effects included in Model 3. In Model 4, predictive effects of Total Toys ($t = 2.65$, $p = .012$) and Highest Level of Play ($t = 4.54$, $p < .001$) were significant. The individual removal of Uses Toys as Agents (Model 4) approached a significant difference in fit when compared against Model 3 ($F = 3.58$, $p = 0.66$). In Model 5, predictive effects of Total Toys ($t = 3.89$, $p < .001$) were significant. Uses Toys as Agents (*p* = .244) was not a significant predictor. The individual removal of Highest Level of Play (Model 5) significantly differed in fit when compared against Model 3 (*F* =

23.40, $p < .001$). In Model 6, predictive effects of Uses Toys as Agents ($t = 5.60$, $p < .001$) were significant. Total Toys ($p = .235$) was not a significant predictor. The individual removal of Total Toys (Model 6) significantly differed in fit when compared against Model 3 ($F = 9.27$, $p = .004$). These comparisons indicate that Model 3 is the current best fitting model. Therefore, Object Substitution was best predicted by Model 3, $F(3, 37) = 23.99$, $p < .001$, adjusted $R^2 = 0.63$. Total Toys ($\beta = 0.10$, $p = .004$) and Highest Level of Play ($\beta = 0.83$, $p < .001$) were significant predictors. Uses Toys as Agents ($\beta = -0.28$, $p = .067$) was not significant.

Unusual Sensory Interest. In Model 1, Chronological Age ($p = .639$), Receptive Language ($p = .703$), Expressive Language ($p = .588$), Fine Motor Skills ($p = .258$), and Non-verbal Intelligence ($p = .622$) were not significant.

In Model 2, predictive effects of Total Toys ($p = .582$), Highest Level of Play ($p = .662$), Uses Toys as Agents ($p = .744$), Object Substitution ($p = .854$), Adult Intervention Required ($p = .339$), and Imitates Modelled Play ($p = .167$) were not significant. Therefore, Unusual Sensory Interest was not predicted by any of the play measures or individual differences across participants.

Adult Intervention Required. In Model 1, Chronological Age ($p = .278$), Receptive Language ($p = .260$), Expressive Language ($p = .551$), Fine Motor Skills ($p = .823$), and Non-verbal Intelligence ($p = .700$) were not significant.

In Model 2, predictive effects of Uses Toys as Agents ($t = 2.98$, $p = .005$) and Imitates Modelled Play ($t = 5.44$, $p < .001$) were significant. Effects of Total Toys ($p = .876$), Highest Level of Play ($p = .239$), Object Substitution ($p = .196$), and Unusual Sensory Interest ($p = .339$) were not significant.

Model 3 contained the two significant fixed effects: Uses Toys as Agents and Imitates Modelled Play. Omitting the non-significant predictors in Model 2 significantly reduced fit in comparison to Model 2 (F = 3.29, p = .022). These comparisons show that Model 2 is the current best fitting model.

Models 4-7 individually added each of the four non-significant fixed effects alongside those included in Model 3. The individual addition of Total Toys (Model 4) significantly differed in fit when compared against Model 2 (F = 3.54, p = .025). The models that individually added Highest Level of Play (Model 5; p = .401) and Object Substitution (Model 6; p = .453) did not significantly differ in fit when compared against Model 2. The individual addition of Unusual Sensory Interest (Model 7) significantly differed in fit when compared against Model 2 (F = 2.14, p = .025). These comparisons indicate that Model 5 and Model 6 are the current joint best fitting models.

Model 8 included four predictive effects: Uses Toys as Agents, Imitates Modelled Play, Highest Level of Play, and Object Substitution. Adding in these measures as predictive effects did not significantly improve predictive fit in comparison to Model 5 (p = .152) or Model 6 (p = .189).

Model 6 was taken as the final model as its adjusted R^2 value (0.786) was fractionally higher than Model 5 (0.784). However, it is noteworthy that Highest Level of Play and Object Substitution were highly correlated (R = 0.75, p < .001), suggesting that the influence of both variables was mediated by a composite effect of overall play sophistication. Therefore, Adult Intervention Required was best predicted by Model 6, F(3, 37) = 50.05, p < .001, adjusted R^2 = 0.79. Uses Toys as Agents (β = -0.48, p < .001), Imitates Modelled Play (β = 0.49, p < .001), and Object Substitution (β = -0.28, p = .002) were significant predictors.

Imitates Modelled Play. In Model 1, Chronological Age (p = .163), Receptive Language (p = .255), Expressive Language (p = .749), Fine Motor Skills (p = .637), and Non-verbal Intelligence (p = .198) were not significant.

In Model 2, the predictive effect of Adult Intervention Required ($t = 5.44$, $p < .001$) was significant. Effects of Total Toys ($p = .959$), Highest Level of Play ($p = .123$), Uses Toys as Agents ($p = .468$), Object Substitution ($p = .795$), and Unusual Sensory Interest ($p = .167$) were not significant. As children's scores for Adult Intervention Required and Imitates Modelled Play were contingent on one another, it was deemed inappropriate to create a third model for this analysis. Therefore, Imitates Modelled Play was not predicted by any of the play measures or individual differences across participants.

Birthday Party

0–1 trials. We began with a baseline model containing by-participant and by-item random intercepts. Fixed effects of Chronological Age (Model 2), Receptive Language (Model 3), Expressive Language (Model 4), Fine Motor Skills (Model 5), and Non-verbal Intelligence (Model 6) were entered individually. The individual addition of Chronological Age ($\chi^2 = 3.40$, $p = .065$) approached a significant improvement in fit when compared with the baseline model. The addition of Receptive Language ($p = .985$), Expressive Language ($p = .510$), Fine Motor Skills ($p = .782$), and Non-verbal Intelligence ($p = .255$) did not improve fit.

Models 7–10 added main effects of Receptive Language, Expressive Language, Fine Motor Skills, and Non-verbal Intelligence individually alongside Chronological Age. The model that added Expressive Language (Model 8; $\chi^2 = 6.00$, $p = .014$) significantly improved fit when compared with Model 2. None of the other models differed significantly from Model 2 (+ Receptive Language: $p = .126$; + Fine Motor Skills: $p = .306$; + Non-verbal Intelligence: $p = .537$). These comparisons show that Model 8 provides the best fit to the observed data.

0–3 trials. We began with a baseline model containing by-participant and by-item random intercepts. Fixed effects of Trial Type (Model 2), Receptive Language (Model 3), Expressive Language (Model 4), Fine Motor Skills (Model 5), and Non-verbal Intelligence

(Model 6) were entered individually. The individual addition of Receptive Language (χ^2 = 5.24, p = .022) and Expressive Language (χ^2 = 4.13, *p* = .042) yielded significant improvements in fit when compared with the baseline model. The addition of Chronological Age (*p* = .097), Fine Motor Skills (*p* = .193), and Non-verbal Intelligence (*p* = .284) did not improve fit.

Model 7 included both of the fixed effects that individually improved predictive fit in comparison to the baseline model: Receptive Language and Expressive Language. The collective addition of these two fixed effects did not significantly improve fit in comparison to Model 3 (*p* = .715) or Model 4 (*p* = .265). These comparisons show that Model 3 and Model 4 are the current joint best fitting models.

Model 3 was taken as the final model as its AIC (345.6) and BIC (361.1) values were lower than those of Model 4 (AIC = 346.7; BIC = 362.2). However, it is noteworthy that Receptive Language and Expressive Language were positively correlated (*R* = 0.77, *p* < .001), suggesting that the influence of both variables was mediated by a composite effect of overall language sophistication. Thus, Model 3 provides the best fit to our observed data.

Social Communication

Response to Name. We began with a model containing Response to Name as the dependent variable with the five remaining social communication measures as predictive effects. Response to Joint Attention (*t* = 2.63, *p* = .013) and Eye Contact (*t* = 3.18, *p* = .003) were statistically significant. Social Smile (*p* = .670), Giving (*p* = .750), and Initiation of Joint Attention (*p* = .168) were not significant.

Model 2 included both of the significant fixed effects: Response to Joint Attention and Eye Contact. Omitting the three non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (*p* = .521).

Fixed effects of Chronological Age (Model 3), Receptive Language (Model 4), Expressive Language (Model 5), Fine Motor Skills (Model 6), and Non-verbal Intelligence (Model 7) were entered individually alongside the fixed effects included in Model 2. The addition of Chronological Age (p = .193), Receptive Language (p = .846), Expressive Language (p = .384), Fine Motor Skills (p = .116), and Non-verbal Intelligence (p = .923) did not improve fit. Therefore, Response to Name was best predicted by Model 2, $F(2, 38)$ = 22.56, $p < .001$, adjusted $R^2 = 0.52$. Response to Joint Attention ($\beta = 0.26$, $p = .022$) and Eye Contact ($\beta = 0.79$, $p < .001$) were both significant predictors.

Response to Joint Attention. We began with a model containing Response to Joint Attention as the dependent variable with the five remaining social communication measures as predictive effects. Response to Name ($t = 2.63$, $p = .013$) was statistically significant. Social Smile (p = .228), Eye Contact (p = .168), Giving (p = .533), and Initiation of Joint Attention (p = .153) were not significant.

Model 2 included Response to Name as a predictor, the only significant fixed effect in the preceding model. Omitting the four non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (p = .250), which indicates that it is the current best fitting model.

Fixed effects of Chronological Age (Model 3), Receptive Language (Model 4), Expressive Language (Model 5), Fine Motor Skills (Model 6), and Non-verbal Intelligence (Model 7) were entered individually alongside the fixed effects included in Model 2. The addition of Chronological Age (p = .434), Receptive Language (p = .531), Expressive Language (p = .652), Fine Motor Skills (p = .531), and Non-verbal Intelligence (p = .710) did not improve fit. Therefore, Response to Joint Attention was best predicted by Model 2, $F(1, 39)$ = 18.14, $p < .001$, adjusted $R^2 = 0.30$. Response to Name was a significant predictor, β = 0.65, $p < .001$.

Social Smile. We began with a model containing Social Smile as the dependent variable with the five remaining social communication measures as predictive effects. Eye Contact (t = 2.62, p = .013) was statistically significant. Response to Name (p = .669), Response to Joint Attention (p = .228), Giving (p = .277), and Initiation of Joint Attention (p = .906) were not significant.

Model 2 included Eye Contact as a predictor, the only significant fixed effect in the preceding model. Omitting the four non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (p = .515), which indicates that it is the current best fitting model.

Fixed effects of Chronological Age (Model 3), Receptive Language (Model 4), Expressive Language (Model 5), Fine Motor Skills (Model 6), and Non-verbal Intelligence (Model 7) were entered individually alongside the fixed effects included in Model 2. The addition of Chronological Age (p = .511), Receptive Language (p = .228), Expressive Language (p = .618), Fine Motor Skills (p = .954), and Non-verbal Intelligence (p = .576) did not improve fit. Therefore, Social Smile was best predicted by Model 2, $F(1, 39) = 13.43$, $p < .001$, adjusted $R^2 = 0.26$. Eye Contact was a significant predictor, $\beta = 1.28$, $p < .001$.

Eye Contact. We began with a model containing Eye Contact as the dependent variable with the five remaining social communication measures as predictive effects. Response to Name (t = 3.18, p = .003) and Social Smile (t = 2.62, p = .013) were statistically significant. Response to Joint Attention (p = .168), Giving (p = .679), and Initiation of Joint Attention (p = .815) were not significant.

Model 2 included both of the significant fixed effects: Response to Name and Social Smile. Omitting the three non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (p = .489), which indicates that it is the current best fitting model.

Fixed effects of Chronological Age (Model 3), Receptive Language (Model 4), Expressive Language (Model 5), Fine Motor Skills (Model 6), and Non-verbal Intelligence (Model 7) were entered individually alongside the fixed effects included in Model 2. The addition of Chronological Age (p = .389), Receptive Language (p = .954), Expressive Language (p = .873), Fine Motor Skills (p = .232), and Non-verbal Intelligence (p = .697) did not improve fit. Therefore, Eye Contact was best predicted by Model 2, $F(2, 38) = 23.69$, $p < .001$, adjusted $R^2 = 0.53$. Response to Name ($\beta = 0.40$ $p < .001$) and Social Smile ($\beta = 0.12$ $p = .013$) were both significant predictors.

Giving. We began with a model containing Giving as the dependent variable with the five remaining social communication measures as predictive effects. Response to Joint Attention (p = .533), Social Smile (p = .277), Response to Name (p = .750), Eye Contact (p = .679), and Initiation of Joint Attention (p = .540) were not significant.

Fixed effects of Chronological Age (Model 2), Receptive Language (Model 3), Expressive Language (Model 4), Fine Motor Skills (Model 5), and Non-verbal Intelligence (Model 6) were entered individually alongside Giving. Predictive effects of Chronological Age (p = .601), Receptive Language (p = .697), Expressive Language (p = .757), Fine Motor Skills (p = .464), and Non-verbal Intelligence (p = .554) were not significant. Therefore, Giving was not predicted by any of the social skills or individual differences across participants.

Initiation of Joint Attention. We began with a model containing Initiation of Joint Attention as the dependent variable with the five remaining social communication measures as predictive effects. Response to Joint Attention (p = .153), Social Smile (p = .906), Response to Name (p = .168), Eye Contact (p = .815), and Response to Joint Attention (p = .153) were not significant.

Fixed effects of Chronological Age (Model 2), Receptive Language (Model 3), Expressive Language (Model 4), Fine Motor Skills (Model 5), and Non-verbal Intelligence (Model 6) were entered individually alongside Giving. Initiation of Joint Attention was significantly predicted by Fine Motor Skills (t = 2.13, p = .039). Predictive effects of Chronological Age (p = .399), Receptive Language (p = .301), Expressive Language (p = .179), and Non-verbal Intelligence (p = .831) were not significant. Therefore, Initiation of Joint Attention was best predicted by Model 5, F(1, 39) = 4.55, p = .039, adjusted R^2 = 0.08. Fine Motor Skills (β = 0.17 p = .039) was a significant predictor.

Study 1: Examining Interrelations Between Domains, NT Only

Picture Comprehension

We began with a baseline model containing Non-verbal Intelligence, as this was identified as significant in the preceding analyses for this task. Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Production (Model 4 = Total Score; Modelled Trials = Model 5; Model 6 = Unmodelled Trials), Social Communication (Model 7 = Raw Score; Model 8 = Response to Name; Model 9 = Response to Joint Attention; Model 10 = Social Smile; Model 11 = Eye Contact; Model 12 = Giving; Model 13 = Initiation of Joint Attention), and Independent Drawing (Model 14) were entered individually alongside Non-verbal Intelligence. The addition of Free Play (p = .886), Birthday Party (p = .063), Picture Production (Total Score: p = .595; Modelled Trials: p = .429; Unmodelled Trials: p = .841), Social Communication (Raw Score: p = .449; Response to Name: p = .253; Response to Joint Attention: p = .133; Social Smile: p = .860; Eye Contact: p = .576; Giving: p = .173; Initiation of Joint Attention: p = .214), and Independent Drawing (p = .544) did not improve fit. These comparisons show that the baseline model, containing only Non-verbal Intelligence as a fixed effect, provides the best fit to our observed data.

Picture Production

We began with a baseline model containing the variables that were identified as significant in the preceding analyses for this task: Trial Type, Chronological Age and Fine Motor Skills. Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4 = Total Score; Same Labels Trials = Model 5; Model 6 = Contrasting Labels Trials), Social Communication (Model 7 = Raw Score; Model 8 = Response to Name; Model 9 = Response to Joint Attention; Model 10 = Social Smile; Model 11 = Eye Contact; Model 12 = Giving; Model 13 = Initiation of Joint Attention), and Independent Drawing (Model 14) were entered individually alongside Non-verbal Intelligence. The individual addition of Free Play ($\chi^2 = 4.25$, $p = .039$) yielded a significant improvement in fit when compared with the baseline model. The addition of Birthday Party ($p = .068$), Picture Comprehension (Total Score: $p = .173$; Same Labels Trials: $p = .425$; Contrasting Labels Trials: $p = .158$), Social Communication (Raw Score: $p = .237$; Response to Name: $p = .426$; Response to Joint Attention: $p = .677$; Social Smile: $p = .149$; Eye Contact: $p = .447$; Giving: $p = .233$; Initiation of Joint Attention: $p = .764$), and Independent Drawing ($p = .549$) did not improve fit.

Models 15-26 individually added each of the non-significant predictors alongside Trial Type, Chronological Age, Fine Motor Skills, and Free Play. None of these models differed significantly from Model 2 (+ Birthday Party: $p = .206$; + Picture Comprehension: $p = .197$; + Same Labels Trials: $p = .537$; + Contrasting Labels Trials: $p = .157$; + Social Communication: $p = .914$; + Response to Name: $p = .890$; + Response to Joint Attention: $p = .482$; + Social Smile: $p = .628$; + Eye Contact: $p = .926$; + Giving: $p = .599$; + Initiation of Joint Attention: $p = .825$; + Independent Drawing: $p = .577$).

These comparisons show that Model 2, containing Trial Type, Chronological Age, Fine Motor Skills, and Free Play as fixed effects, provides the best fit to our observed data.

Total Toys. We began with a baseline model containing Non-verbal Intelligence and Object Substitution alongside Total Toys, as both these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. The inclusion of Independent Drawing in Model 8 (F = 3.42, p = .072) approached a significant improvement in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: p = .463; + Same Labels Trials: p = .687; + Contrasting Labels Trials: p = .204; + Picture Production: p = .174; + Modelled Trials: p = 390; + Unmodelled Trials: p = .109; + Social Communication: p = .085; + Response to Name: p = .678; + Response to Joint Attention: p = .114; + Social Smile: p = .695; + Eye Contact: p = .169; + Giving: p = .157; + Initiation of Joint Attention: p = .496).

Model 8 was taken as the final best-fitting model for Total Toys, $F(3, 37)$ = 15.97, p < .001, adjusted R^2 = 0.53. Non-verbal Intelligence (β = 0.09 p = .035) and Object Substitution (β = 2.21, p < .001) were significant predictors. Independent Drawing (β = 0.30 p = .072) approached significance.

Highest Level of Play. We began with a baseline model containing Uses Toys as Agents and Object Substitution alongside Highest Level of Play, as both these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. The inclusion of Social Smile in Model 12 (F = 3.46, p = .071) approached a significant improvement in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: p = .648; + Same Labels Trials: p = .737; + Contrasting Labels Trials: p = .366; + Picture Production: p = .595; + Modelled Trials: p = 383; Unmodelled Trials: p = .915; + Independent Drawing: p = .433; + Social Communication: p = .434; + Response to Name: p = .202; + Response to Joint Attention: p = .980; + Eye Contact: p = .632; + Giving: p = .928; + Initiation of Joint Attention: p = .180).

Model 12 was taken as the final best-fitting model for Highest Level of Play, $F(3, 37)$ = 43.51, p < .001, adjusted R^2 = 0.76. Uses Toys as Agents (β = 0.43 p < .001), Object Substitution (β = 0.41, p < .001) were significant predictors. Social Smile (β = 0.09, p = .071) approached significance.

Uses Toys as Agents. We began with a baseline model containing Highest Level of Play, Object Substitution, and Adult Intervention Required, as these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social

Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. The inclusion of Picture Production (Model 5; $F = 8.23$, $p = .007$), Modelled Trials (Model 6; $F = 6.61$, $p = .014$), Unmodelled Trials (Model 7; $F = 6.76$, $p = .013$), Independent Drawing (Model 8; $F = 4.03$, $p = .052$), and Social Smile (Model 12; $F = 3.91$, $p = .056$) yielded, or approached, significant improvements in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: $p = .884$; + Same Labels Trials: $p = .536$; + Contrasting Labels Trials: $p = .829$; + Social Communication: $p = .813$; + Response to Name: $p = .100$; + Response to Joint Attention: $p = .565$; + Eye Contact: $p = .546$; + Giving: $p = .533$; + Initiation of Joint Attention: $p = .376$). These comparisons show that Models 5, 6, 7, 8, and 12 are the current best fitting models.

Model 16 contained Picture Production, Independent Drawing, and Social Smile alongside the predictive effects in the baseline model. Modelled Trials and Unmodelled Trials (significant effects in Models 6 and 7) were not included in Model 16 because Picture Production was a composite score that captured performance on both these trial types, and all three of these fixed effects were individually significant predictors. Adding the significant and borderline significant effects in Model 16 significantly improved fit in comparison to Model 8 ($F = 3.60$, $p = .038$) and Model 12 ($F = 3.66$, $p = .036$), but did not significantly improve fit in comparison to Model 5 ($p = .209$). These comparisons show that Model 5 is the current best fitting model.

Models 17-18 individually added Independent Drawing and Social Smile alongside the fixed effects in Model 5. Neither of these two models significantly improved fit compared to Model 5 (Model 17: $p = .692$; Model 18; $p = .076$).

Therefore, Model 5 was taken as the final best-fitting model for Uses Toys as Agents, $F(4, 36) = 26.62$, $p < .001$, adjusted $R^2 = 0.72$. Highest Level of Play ($\beta = 0.62$ $p = .001$), Object Substitution ($\beta = -0.35$, $p = .011$), Adult Intervention Required ($\beta = -0.50$, $p < .001$), and Picture Production ($\beta = 0.06$, $p = .007$) were significant predictors.

Object Substitution. We began with a baseline model containing Total Toys, Highest Level of Play, and Uses Toys as Agents, as these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. None of the models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: $p = .395$; + Same Labels Trials: $p = .946$; + Contrasting Labels Trials: $p = .233$; + Picture Production: $p = .636$; + Modelled Trials: $p = .378$; Unmodelled Trials: $p = .989$; + Independent Drawing: $p = .770$; + Social Communication: $p = .488$; + Response to Name: $p = .921$; + Response to Joint Attention: $p = .720$; + Social Smile: $p = .737$; + Eye Contact: $p = .392$; + Giving: $p = .598$; + Initiation of Joint Attention: $p = .364$), so the baseline model was taken as the final model.

Unusual Sensory Interest. As there were no predictive effects identified as significant in the preceding analyses of individual differences for this task, fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to

Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside Unusual Sensory Interest.

The inclusion of Social Smile (Model 5; $F = 5.39$, $p = .0.26$) yielded a significant improvement in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: $p = .911$; + Same Labels Trials: $p = .697$ + Contrasting Labels Trials: $p = .663$; + Picture Production: $p = .708$; + Modelled Trials: $p = 1.00$; Unmodelled Trials: $p = .500$; + Independent Drawing: $p = .443$; + Social Communication: $p = .329$; + Response to Name: $p = .824$; + Response to Joint Attention: $p = .594$; + Eye Contact: $p = .747$; + Giving: $p = .552$; + Initiation of Joint Attention: $p = .678$).

Model 11 was taken as the final best-fitting model for Unusual Sensory Interest, $F(1, 39) = 5.39$, $p = .026$, adjusted $R^2 = 0.10$. Social Smile ($\beta = -0.07$ $p = .026$) was a significant predictor.

Adult Intervention Required. We began with a baseline model containing Uses Toys as Agents, Imitates Modelled Play, and Object Substitution, as these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. The inclusion of Social Smile (Model 12; $F = 5.64$, $p = .023$), yielded a significant improvement in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: p = .146; + Same Labels Trials: p = .077; + Contrasting Labels Trials: p = .379; + Picture Production: p = .604; + Modelled Trials: p = .583; Unmodelled Trials: p = .702; + Independent Drawing: p = .179; + Social Communication: p = .200; + Response to Name: p = .954; + Response to Joint Attention: p = .781; + Eye Contact: p = .907; + Giving: p = .613; + Initiation of Joint Attention: p = .944).

Model 12 was taken as the final best-fitting model for Adult Intervention Required, $F(4, 36) = 43.65$, $p < .001$, adjusted $R^2 = 0.81$. Uses Toys as Agents (β = -0.46 $p < .001$), Imitates Modelled Play (β = 0.43, $p < .001$), Object Substitution (β = -0.23 p = .009), and Social Smile (β = -0.12 p = .023) were significant predictors.

Imitates Modelled Play. We began with a baseline model containing Adult Intervention Required, as this was the only predictive effect that was identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. The inclusion of Picture Production (Model 12; F = 5.06, p = .030) and Unmodelled Trials (Model 6; F = 5.33, p = .026) yielded significant improvements in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: p = .393; + Same Labels Trials: p = .487; + Contrasting Labels Trials: p = .450; + Modelled Trials: p = .081; + Independent Drawing: p = .566; + Social Communication: p = .983; + Response to Name: p

= .771; + Response to Joint Attention: p = .711; + Social Smile: p = .923; + Eye Contact: p = .176; + Giving: p = .608; + Initiation of Joint Attention: p = .907). These comparisons show that Models 5 and 6 are the current joint best fitting models.

As Picture Production was a composite score that captured performance on both unmodelled and modelled trials, and the latter was not an individually significant predictor, its predictive contribution was likely driven by the Unmodelled Trials. Consequently, Model 6 was taken as the final best-fitting model for Imitates Modelled Play, $F(2, 38) = 19.65$, $p < .001$, adjusted $R^2 = 0.48$. Adult Intervention Required ($\beta = 0.62$, $p < .001$) and Unmodelled Trials ($\beta = 0.10$ $p = .027$) were significant predictors.

Birthday Party

0–1 trials. We began with a baseline model containing Chronological Age and Expressive Language, as these were the only two variables that were identified as significant in the preceding analyses for this task, plus by-participant and by-item random intercepts. Fixed effects of Free Play (Model 2), Picture Comprehension (Model 3), Same Labels Trials (Model 4), Contrasting Labels Trials (Model 5), Picture Production (Model 6), Modelled Trials (Model 7), Unmodelled Trials (Model 8), Independent Drawing (Model 9), Social Communication (Model 10), Response to Name (Model 11), Response to Joint Attention (Model 12), Social Smile (Model 13), Eye Contact (Model 14), Giving (Model 15), and Initiation of Joint Attention (Model 16) were entered individually alongside Chronological Age and Expressive Language. The individual addition of Free Play ($\chi^2 = 5.01$, $p = .025$) and Eye Contact ($\chi^2 = 3.31$, $p = .069$) yielded significant or borderline significant improvements in fit when compared with the baseline model. None of the other models improved fit when compared with the baseline model (+ Picture Comprehension: p = .142; + Same Labels Trials: p = 1.00; + Contrasting Labels Trials: p = .476; + Picture Production: p = .330; + Modelled Trials: p = .350; + Unmodelled Trials: p = .450; + Independent Drawing: p = .827;

+ Social Communication: $p = .097$; + Response to Name: $p = .138$; + Response to Joint Attention: $p = .872$; + Social Smile: $p = .146$; + Giving: $p = .132$; + Initiation of Joint Attention: $p = .680$).

Model 17 added both of the borderline/significant predictors alongside Chronological Age and Expressive Language. The collective addition of both Free Play and Eye Contact approached a significant improvement in fit when compared with Model 14 ($\chi^2 = 3.25$, $p = .071$), but did not differ in fit when compared with Model 2 ($p = .213$). These comparisons show that Model 2 provides the best fit to our observed data.

0–3 trials. We began with a baseline model containing Receptive Language, as this was the only variable that was identified as significant in the preceding analyses for this task, plus by-participant and by-item random intercepts. Fixed effects of Free Play (Model 2), Picture Comprehension (Model 3), Same Labels Trials (Model 4), Contrasting Labels Trials (Model 5), Picture Production (Model 6), Modelled Trials (Model 7), Unmodelled Trials (Model 8), Independent Drawing (Model 9), Social Communication (Model 10), Response to Name (Model 11), Response to Joint Attention (Model 12), Social Smile (Model 13), Eye Contact (Model 14), Giving (Model 15), and Initiation of Joint Attention (Model 16) were entered individually alongside Receptive Language. The individual addition of Picture Comprehension ($\chi^2 = 4.74$, $p = .029$) and Contrasting Labels Trials ($\chi^2 = 5.29$, $p = .021$) yielded significant improvements in fit when compared with the baseline model. The addition of Free Play ($p = .478$), Same Labels Trials ($p = .225$), Picture Production ($p = .191$), Modelled Trials ($p = .453$), Unmodelled Trials ($p = .105$), Independent Drawing ($p = .848$), Social Communication ($p = .479$), Response to Name ($p = .938$), Response to Joint Attention ($p = .185$), Social Smile ($p = .086$), Eye Contact ($p = .633$), Giving ($p = .174$), and Initiation of Joint Attention ($p = .868$) did not improve fit. These comparisons show that Model 3 and Model 5 are the current joint best fitting models.

As Picture Comprehension was a composite score that captured performance on both Same Labels and Contrasting Labels Trials, and the former was not an individually significant predictor, its predictive effect appears to be driven by the Contrasting Labels Trials. Consequently, Model 5 was taken as the final best-fitting model of our observed data.

Social Communication

Response to Name. We began with a baseline model containing Response to Joint Attention and Eye Contact alongside Response to Name, as both these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4), Same Labels Trials (Model 5), Contrasting Labels Trials (Model 6), Picture Production (Model 7), Modelled Trials (Model 8), Unmodelled Trials (Model 9), and Independent Drawing (Model 10) were entered individually alongside the fixed effects included in the baseline model. The inclusion of Picture Production in Model 7 (F = 4.17, p = .048) and Modelled Trials in Model 3 (F = 7.73, p = .008) yielded significant improvements in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Free Play: p = .319; + Birthday Party: p = .434; + Picture Comprehension: p = .710; + Same Labels Trials: p = .981; + Contrasting Labels Trials: p = .566; + Unmodelled Trials: p = .263; + Independent Drawing: p = .777). These comparisons show that Models 7 and 8 are the current joint best fitting models.

As Picture Production was a composite score that captured performance on both modelled and unmodelled trials, and the latter was not an individually significant predictor, its predictive effect appears to be driven by the Modelled Trials. Consequently, Model 8 was taken as the final best-fitting model for Response to Name, $F(3, 37) = 20.28$, $p < .001$, adjusted $R^2 = 0.59$. Response to Joint Attention (β = 0.23 p = .032), Eye Contact (β = 0.75, p < .001) and Modelled Trials (β = 0.11 p = .008) were significant predictors.

Response to Joint Attention. We began with a baseline model containing Response to Name, as this was the only predictive effect that was identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4), Same Labels Trials (Model 5), Contrasting Labels Trials (Model 6), Picture Production (Model 7), Modelled Trials (Model 8), Unmodelled Trials (Model 9), and Independent Drawing (Model 10) were entered individually alongside the fixed effects included in the baseline model. None of these models significantly differed in fit when compared with the baseline model (+ Free Play: p = .753; + Birthday Party: p = .304; + Picture Comprehension: p = .397; + Same Labels Trials: p = .976; + Contrasting Labels Trials: p = .198; Picture Production: p = .798; + Modelled Trials: p = .669; + Unmodelled Trials: p = .942; + Independent Drawing: p = .436), so the baseline model was taken as the final model.

Social Smile. We began with a baseline model containing Eye Contact, as this was the only predictive effect that was identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4), Same Labels Trials (Model 5), Contrasting Labels Trials (Model 6), Picture Production (Model 7), Modelled Trials (Model 8), Unmodelled Trials (Model 9), and Independent Drawing (Model 10) were entered individually alongside the fixed effects included in the baseline model. The inclusion of Free Play in Model 2 (F = 4.38, p = .043) and Birthday Party in Model 3 (F = 6.86, p = .013) yielded significant improvements in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: p = .504; + Same Labels Trials: p = .413; + Contrasting Labels Trials: p = .684; Picture Production: p = .708; +

Modelled Trials: p = .927; + Unmodelled Trials: p = .557; + Independent Drawing: p = .459). These comparisons show that Models 2 and 3 are the current joint best fitting models.

Model 11, which contained both Free Play and Birthday Party alongside Social Smile, approached a significant improvement in predictive fit in comparison to Model 2 (F = 3.94, p = .055), but did not improve fit in comparison to Model 3. Therefore, Social Smile was best predicted by Model 3, $F(2, 38) = 11.15$, $p < .001$, adjusted $R^2 = 0.34$. Eye Contact (β = 1.23 p = .001) and Birthday Party (β = 0.12, p = .013) were both significant predictors.

Eye Contact. We began with a baseline model containing Response to Name and Social Smile, as both these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4), Same Labels Trials (Model 5), Contrasting Labels Trials (Model 6), Picture Production (Model 7), Modelled Trials (Model 8), Unmodelled Trials (Model 9), and Independent Drawing (Model 10) were entered individually alongside the fixed effects included in the baseline model. None of these models significantly differed in fit when compared with the baseline model (+ Free Play: p = .581; + Birthday Party: p = .298; + Picture Comprehension: p = .593; + Same Labels Trials: p = .829; + Contrasting Labels Trials: p = .948; Picture Production: p = .257; + Modelled Trials: p = .240; + Unmodelled Trials: p = .344; + Independent Drawing: p = .793), so the baseline model was taken as the final model.

Giving. As there were no predictive effects identified as significant in the preceding analyses of individual differences for this task, fixed effects of Free Play (Model 1), Birthday Party (Model 2), Picture Comprehension (Model 3), Same Labels Trials (Model 4), Contrasting Labels Trials (Model 5), Picture Production (Model 6), Modelled Trials (Model 7), Unmodelled Trials (Model 8), and Independent Drawing (Model 9) were entered as individual fixed effects. Only Free Play was identified as a significant predictor of Giving (t = 2.68, p = .011). Predictive effects of Birthday Party (p = .164), Picture Comprehension (p = .332), Same Labels Trials (p = .860), Contrasting Labels Trials (p = .196), Picture Production (p = .182), Modelled Trials (p = .352), Unmodelled Trials (p = .128), and Independent Drawing (p = .394) were not significant. Therefore, Giving was best predicted by Model 1 $F(1, 39) = 7.17$, p = .011, adjusted $R^2 = 0.13$. Free Play ($\beta = 0.14$ p = .011) was a significant predictor.

Initiation of Joint Attention. We began with a baseline model containing Fine Motor Skills, as this predictive effect was identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4), Same Labels Trials (Model 5), Contrasting Labels Trials (Model 6), Picture Production (Model 7), Modelled Trials (Model 8), Unmodelled Trials (Model 9), and Independent Drawing (Model 10) were entered individually alongside the fixed effects included in the baseline model. None of these models significantly differed in fit when compared with the baseline model (+ Free Play: p = .996; + Birthday Party: p = .992; + Picture Comprehension: p = .650; + Same Labels Trials: p = .948; + Contrasting Labels Trials: p = .489; Picture Production: p = .504; + Modelled Trials: p = .249; + Unmodelled Trials: p = .980; + Independent Drawing: p = .146), so the baseline model was taken as the final model.

Study 2: Examining Individual Differences Within Domains, ASD Only

Picture Comprehension

We began with a baseline model containing by-participant and by-item random intercepts. Fixed effects of Trial Type (Model 2), Trial Number (Model 3), Chronological

Age (Model 4), Receptive Language (Model 5), Expressive Language (Model 6), Fine Motor Skills (Model 7), Non-Verbal Intelligence (Model 8), and CARS Score (Model 9) were entered individually. The individual addition of Trial Type ($\chi^2 = 6.35$, $p = .012$) and Fine Motor Skills ($\chi^2 = 4.24$, $p = .040$) yielded significant improvements in fit when compared with the baseline model. The individual addition of Receptive Language ($\chi^2 = 3.82$, $p = .051$) and Non-verbal Intelligence ($\chi^2 = 3.59$, $p = .058$) approached significant improvements in fit when compared with the baseline model. The addition of Trial Number ($p = .479$), Chronological Age ($p = .259$), Expressive Language ($p = .150$), and CARS Score ($p = .242$) did not improve fit.

Model 10 included both of the fixed effects that individually improved predictive fit in comparison to the baseline model (Trial Type and Fine Motor Skills), as well as the two fixed effects that approached significance (Receptive Language and Non-verbal Intelligence). Model 10 did not significantly differ in fit when compared against Model 2 ($p = .181$), but approached significance in comparison to Model 5 ($p = .060$), Model 7 ($p = .072$), and Model 8 ($p = .054$).

Next, we individually added each of the seven fixed effects alongside Trial Type. The individual addition of Fine Motor Skills (Model 14; $\chi^2 = 4.23$; $p = .040$) yielded a significant improvement in fit when compared with Model 2. The individual addition of Receptive Language (Model 12; $\chi^2 = 3.83$; $p = .050$) and Non-verbal Intelligence (Model 15; $p = .057$) approached significance in comparison to Model 2. The addition of Chronological Age (Model 11; $p = .260$), Expressive Language (Model 13, $p = .085$), and CARS Score (Model 16; $p = .139$) did not improve fit when compared with Model 2. These comparisons show that 14 is the current best fitting model.

Models 17 and 18 individually added each of the fixed effects that approached significance alongside Trial Type and Fine Motor Skills. The addition of Receptive Language

(Model 17; p = .535) and Non-verbal Intelligence (Model 18; p = .560) did not significantly differ in fit when compared against Model 14. Models 19-21 individually added each of the remaining three fixed effects alongside Trial Type and Fine Motor Skills. The addition of CARS Score (Model 21) approached a significant improvement in fit when compared with Model 14 (p = .075). The addition of Chronological Age (Model 19; p = 1.00) and Expressive Language (Model 20; p = .504) did not significantly differ in fit when compared against Model 14. These comparisons show that Model 21 is the current best fitting model.

Models 22-25 individually added each of the remaining four fixed effects alongside Trial Type, Fine Motor Skills, and CARS Score. None of these models differed significantly from Model 21 (+ Chronological Age: p = .128; Addition of Receptive Language: p = .577; + Expressive Language: p = .492; + Non-verbal Intelligence: p = .393). These comparisons show that Model 21 is the current best fitting model. Therefore, Model 21 provides the best fit to the observed data.

Picture Production

We began with a baseline model containing by-participant and by-item random intercepts. Fixed effects of Trial Type (Model 2), Trial Number (Model 3), Chronological Age (Model 4), Receptive Language (Model 5), Expressive Language (Model 6), Fine Motor Skills (Model 7), Non-Verbal Intelligence (Model 8), and CARS Score (Model 9) were entered individually. The individual addition of Trial Type (χ^2 = 8.38, p = .004), Chronological Age (χ^2 = 7.01, p = .008), Receptive Language (χ^2 = 7.47, p = .006), Expressive Language (χ^2 = 6.10, p = .013), Fine Motor Skills (χ^2 = 15.86, p < .001), and Non-Verbal Intelligence (χ^2 = 15.57, p < .001), yielded significant improvements in fit when compared with the baseline model. The addition of Trial Number (p = .756), and CARS Score (p = .453) did not improve fit.

Model 10 included all of the fixed effects that individually improved predictive fit in comparison to the baseline model: Trial Type, Chronological Age, Receptive Language, Expressive Language, Fine Motor Skills, and Non-Verbal Intelligence. The collective addition of fixed effects significantly improved fit in comparison to Model 2 (χ^2 = 19.85, p = .001), Model 4 (χ^2 = 21.22, p = .001), Model 5 (χ^2 = 20.76, p = .001), Model 6 (χ^2 = 22.13, p < .001), Model 7 (χ^2 = 12.38, p = .030) and Model 8 (χ^2 = 12.67, p = .027). Therefore Model 10 is the current best fitting model.

To establish the most parsimonious model predicting children's picture production, Models 11-16 individually removed each of the significant fixed effects that improved predictive fit to identify whether any effects are dispensable. The removal of Trial Type (Model 11; χ^2 = 8.64, p = .003) yielded significant reductions in fit in comparison to Model 10. The removal of Chronological Age (Model 12, p = .310), Receptive Language (Model 13; p = .586), Expressive Language (Model 14; p = .877), Fine Motor Skills (Model 15; p = .103), and Non-verbal Intelligence (Model 16; p = .156) did not reduce fit. As Models 12-16 contained fewer fixed effects but did not differ in the amount of variability predicted, these models are the current best fitting.

Next, we individually added each of the five fixed effects alongside Trial Type. The model that added Chronological Age (Model 17) was significantly worse-fitting than Model 12 (χ^2 = 11.58, p = .009), Model 13 (χ^2 = 12.31, p = .006), Model 14 (12.58, p = .006), Model 15 (9.95, p = .019), and Model 16 (10.59, p = .014). The model that added Receptive Language (Model 18) was significantly worse-fitting than Model 12 (χ^2 = 10.88, p = .012), Model 13 (χ^2 = 11.62, p = .009), Model 14 (11.89, p = .008), Model 15 (9.25, p = .026) and Model 16 (9.86, p = .020). The model that added Expressive Language (Model 19) was significantly worse-fitting than Model 12 (χ^2 = 12.15, p = .007), Model 13 (χ^2 = 12.88, p = .005), Model 14 (13.15, p = .004), Model 15 (10.52, p = .015) and Model 16 (11.12, p =

.011). The model that added Fine Motor Skills (Model 20) did not significantly differ in fit when compared to Model 12 (p = .476), Model 13 (p = .357), Model 14 (p = .321), Model 15 (p = .833), and Model 16 (p = .679). The model that added Non-verbal Intelligence (Model 21) did not significantly differ in fit when compared to Model 12 (p = .357), Model 13 (p = .265), Model 14 (p = .237), Model 15 (p = .658), and Model 16 (p = .522). These comparisons show that Models 20 and 21 are the current best fitting.

Model 22 included Trial Type, Fine Motor Skills, and Non-verbal Intelligence as fixed effects. This did not differ from either Model 20 (p = .123) or Model 21 (p = .077).

Model 20, containing Trial Type and Fine Motor Skills as fixed effects, was taken as the final model as its AIC (151.6) and BIC (167.0) values were lower than the model containing Trial Type and Non-verbal Intelligence (AIC = 152.3; BIC = 167.7). However, it is noteworthy that Fine Motor Skills and Non-verbal Intelligence were highly correlated (R = 0.81, $p < .001$), suggesting that both variables could potentially influence Picture Production. Thus, Model 20 provides the best fit to our observed data.

Free Play

Total Toys. We began with a model containing Total Toys as the dependent variable with six predictive effects: Chronological Age, Receptive Language, Expressive Language, Fine Motor, Non-verbal Intelligence, and CARS Score. Chronological Age (p = .287), Receptive Language (p = .548), Expressive Language (p = .295), Fine Motor Skills (p = .350), Non-verbal Intelligence (p = .707), and CARS Score (p = .629) were not significant.

As none of the measures of individual differences were identified as significant predictors, Model 2 contained six predictive effects: Highest Level of Play, Uses Toys as Agents, Object Substitution, Unusual Sensory Interest, Adult Intervention Required, and Imitates Modelled Play. The predictive effect of Highest Level of Play (t = 3.01, p = .007) was significant. Predictive effects of Uses Toys as Agents (p = .790), Object Substitution (p =

.397), Unusual Sensory Interest (p = .373), Adult Intervention Required (p = .814), and Imitates Modelled Play (p = .225) were not significant.

Model 3 contained only Highest Level of Play as a predictive effect, which was significant (t = 5.41, p < .001). Omitting the five non-significant measures as predictive effects did not significantly reduce predictive fit in comparison to Model 2 (p = .389). Therefore, Total Toys was best predicted by Model 3, $F(1, 25) = 29.23$, p < .001, adjusted R^2 = 0.52. Highest Level of Play (β = 1.67 p < .001) was a significant predictor.

Highest Level of Play. We began with a model containing Highest Level of Play as the dependent variable with six predictive effects: Chronological Age, Receptive Language, Expressive Language, Fine Motor, Non-verbal Intelligence, and CARS Score. Chronological Age (t = 2.02, p = .057) approached significance. Receptive Language (p = .777), Expressive Language (p = .946), Fine Motor Skills (p = .536), Non-verbal Intelligence (p = .272), and CARS Score (p = .184) were not significant.

Model 2 contained only Chronological Age as a predictive effect, which was significant (t = 3.10, p = .005). Omitting the five non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (p = .635), which indicates that it is the current best fitting model.

Model 3 contained seven predictive effects: Chronological Age, Total Toys, Uses Toys as Agents, Object Substitution, Unusual Sensory Interest, Adult Intervention Required, and Imitates Modelled Play. Predictive effects of Total Toys (t = 2.70, p = .014) and Uses Toys as Agents (t = 2.07, p = .052) were significant, or borderline significant. Predictive effects of Chronological Age (p = .784), Object Substitution **(**p = .207), Unusual Sensory Interest (p = .622), Adult Intervention Required (p = .361), and Imitates Modelled Play (p = .073) were not significant.

Model 4 contained the two significant predictive effects: Total Toys and Uses Toys as Agents, which were significant (Total Toys: $t = 3.26$, $p = .003$; Uses Toys as Agents: $t = 2.91$, $p =.008$). Omitting the four non-significant measures as predictive effects did not significantly reduce predictive fit in comparison to Model 3 ($p = .240$). Therefore, Highest Level of Play was best predicted by Model 4, $F(2, 24) = 23.19$, $p < .001$, adjusted $R^2 = 0.63$. Total Toys ($\beta = 0.21$ $p = .003$) and Uses Toys as Agents ($\beta = 0.63$ $p = .008$) were both significant predictors.

Uses Toys as Agents. We began with a model containing Uses Toys as Agents as the dependent variable with six predictive effects: Chronological Age, Receptive Language, Expressive Language, Fine Motor, Non-verbal Intelligence, and CARS Score. Chronological Age ($p = .492$), Receptive Language ($p = .755$), Expressive Language ($p = .963$), Fine Motor Skills ($p = .760$), Non-verbal Intelligence ($p = .553$), and CARS Score ($p = .337$) were not significant.

As none of the measures of individual differences were identified as significant predictors, Model 2 contained six predictive effects: Total Toys, Highest Level of Play, Object Substitution, Unusual Sensory Interest, Adult Intervention Required, and Imitates Modelled Play. Predictive effects of Highest Level of Play ($t = 2.10$, $p = .049$) and Object Substitution ($t = 5.92$, $p < .001$) were significant. Predictive effects of Total Toys ($p = .790$), Unusual Sensory Interest ($p = .199$), Adult Intervention Required ($p = .467$), and Imitates Modelled Play ($p = .898$) were not significant.

Model 3 contained the two significant predictive effects: Highest Level of Play and Object Substitution, which were significant (Highest Level of Play: $t = 2.25$, $p = .034$; Object Substitution: $t = 6.77$, $p < .001$). Omitting the four non-significant measures as predictive effects did not significantly reduce predictive fit in comparison to Model 2 ($p = .561$). Therefore, Uses Toys as Agents was best predicted by Model 3, $F(2, 24) = 59.08$, $p < .001$, adjusted R^2 = 0.82. Highest Level of Play (β = 0.17, p = .034), and Object Substitution (β = 0.79, p < .001) were significant predictors.

Object Substitution. We began with a model containing Object Substitution as the dependent variable with six predictive effects: Chronological Age, Receptive Language, Expressive Language, Fine Motor, Non-verbal Intelligence, and CARS Score. Chronological Age (p = .562), Receptive Language (p = .229), Expressive Language (p = .706), Fine Motor Skills (p = .177), Non-verbal Intelligence (p = .973), and CARS Score (p = .713) were not significant.

As none of the measures of individual differences were identified as significant predictors, Model 2 contained six predictive effects: Total Toys, Highest Level of Play, Uses Toys as Agents, Unusual Sensory Interest, Adult Intervention Required, and Imitates Modelled Play. Predictive effects of Uses Toys as Agents (t = 5.92, p < .001) and Adult Intervention Required (t = 2.31, p = .032) were significant. Predictive effects of Total Toys (p = .397), Highest Level of Play (p = .157) Unusual Sensory Interest (p = .228), and Imitates Modelled Play (p = .642) were not significant.

Model 3 contained the two significant predictive effects: Uses Toys as Agents and Adult Intervention Required, which were significant (Uses Toys as Agents: t = 6.47, p < .001; Adult Intervention Required: t = 2.70, p = .012. Omitting the four non-significant measures as predictive effects did not significantly reduce predictive fit in comparison to Model 2 (p = .445). Therefore, Object Substitution was best predicted by Model 3, F(2, 24) = 64.52, p < .001, adjusted R^2 = 0.83. Uses Toys as Agents (β = 0.65, p < .001) and Adult Intervention Required (β = -0.29, p = .012) were significant predictors.

Unusual Sensory Interest. We began with a model containing Unusual Sensory Interest as the dependent variable with six predictive effects: Chronological Age, Receptive Language, Expressive Language, Fine Motor, Non-verbal Intelligence, and CARS Score.

Chronological Age (p = .068) approached significance. Receptive Language (p = .723), Expressive Language (p = .627), Fine Motor Skills (p = .103), Non-verbal Intelligence (p = .138), and CARS Score (p = .855) were not significant.

Model 2 contained only Chronological Age as a predictive effect, which was significant (t = 2.86, p = .008). Omitting the five non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (p = .635), which indicates that it is the current best fitting model.

Model 3 contained seven predictive effects: Chronological Age, Total Toys, Highest Level of Play, Uses Toys as Agents, Object Substitution, Adult Intervention Required, and Imitates Modelled Play. The predictive effect of Chronological Age (t = 1.93, p = .068) approached significance. Predictive effects of Total Toys (p = .373), Highest Level of Play (p = .495), Uses Toys as Agents (p = .199), Object Substitution (p = .228), Adult Intervention Required (p = .713), and Imitates Modelled Play (p = .388) were not significant. Adding the six non-significant measures as predictive effects did not significantly improve predictive fit in comparison to Model 2 (p = .344). Therefore, Unusual Sensory Interest was best predicted by Model 2 $F(1, 25) = 8.20$, p = .008, adjusted R^2 = 0.22.

Adult Intervention Required. We began with a model containing Adult Intervention Required as the dependent variable with six predictive effects: Chronological Age, Receptive Language, Expressive Language, Fine Motor, Non-verbal Intelligence, and CARS Score. Chronological Age (t = 2.35, p = .029) was significant. Receptive Language (p = .181), Expressive Language (p = .898), Fine Motor Skills (p = .569), Non-verbal Intelligence (p = .053), and CARS Score (p = .577) were not significant.

Model 2 contained Chronological Age and Non-verbal Intelligence as predictive effects, which were significant (Chronological Age: t = 3.10, p = .005; Non-verbal Intelligence: t = 2.31, p = .030). Omitting the four non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (p = .417), which indicates that it is the current best fitting model.

Model 3 contained eight predictive effects: Chronological Age, Non-verbal Intelligence, Total Toys, Highest Level of Play, Uses Toys as Agents, Object Substitution, Unusual Sensory Interest, and Imitates Modelled Play. Predictive effects of Chronological Age (t = 3.26, p = .004), Non-verbal Intelligence (t = 2.59, p = .018) and Object Substitution (t = 2.31, p = .033) were significant. Predictive effects of Total Toys (p = .724), Highest Level of Play (p = .925), Uses Toys as Agents (p = .884), Unusual Sensory Interest (p = .875), and Imitates Modelled Play (p = .436) were not significant.

Model 4 contained the three significant predictive effects: Chronological Age, Non-verbal Intelligence, and Object Substitution. Predictive effects of Chronological Age (t = 4.35, p < .001), Non-verbal Intelligence (t = 2.98, p = .007), and Object Substitution (t = 6.79, p < .001) were significant. Omitting the five non-significant measures as predictive effects did not significantly reduce predictive fit in comparison to Model 3 (F = 0.24, p = .938). Therefore, Adult Intervention Required was best predicted by Model 4, F(3, 23) = 25.27, p < .001, adjusted R^2 = 0.74. Chronological Age (β = -0.01, p < .001), Non-verbal Intelligence (β = 0.01, p = .007), and Object Substitution (β = -0.69, p < .001) were significant predictors.

Imitates Modelled Play. We began with a model containing Imitates Modelled Play as the dependent variable with six predictive effects: Chronological Age, Receptive Language, Expressive Language, Fine Motor, Non-verbal Intelligence, and CARS Score. CARS Score (t = 2.13, p = .046) was a significant predictor. Chronological Age (p = .124), Receptive Language (p = .159), Expressive Language (p = .184), Fine Motor Skills (p = .984), and Non-verbal Intelligence (p = .802) were not significant.

Model 2 contained the only significant predictor: CARS Score. Omitting the five non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (p = .453), however predictive effect of CARS Score (p = .103) was not significant. Model 3 contained seven predictive effects: CARS Score, Total Toys, Highest Level of Play, Uses Toys as Agents, Object Substitution, Unusual Sensory Interest, and Adult Intervention Required. The predictive effect of Highest Level of Play (p = .057) approached significance. Predictive effects of CARS Score (p = .155), Total Toys (p = .225), Uses Toys as Agents (p = .898), Object Substitution (p = .642), Unusual Sensory Interest (p = .389), and Adult Intervention Required (p = .801) were not significant.

Model 3 contained seven predictive effects: CARS Score, Total Toys, Highest Level of Play, Uses Toys as Agents, Object Substitution, Unusual Sensory Interest, and Adult Intervention Required. The predictive effect of Highest Level of Play (p = .057) approached significance. Predictive effects of CARS Score (p = .155), Total Toys (p = .225), Uses Toys as Agents (p = .898), Object Substitution (p = .642), Unusual Sensory Interest (p = .389), and Adult Intervention Required (p = .801) were not significant.

Model 4 contained Highest Level of Play as a predictive effect, which was significant (t = 2.81, p = .010). Therefore, Imitates Modelled Play was best predicted by Model 4, F(1, 25) = 7.63, p =.011, adjusted R^2 = 0.20. Highest Level of Play (β = -0.38, p = .011) was a significant predictor.

Birthday Party

0–1 trials. We began with a baseline model containing by-participant and by-item random intercepts. Fixed effects of Chronological Age (Model 2), Receptive Language (Model 3), Expressive Language (Model 4), Fine Motor Skills (Model 5), Non-verbal Intelligence (Model 6), and CARS Score (Model 7) were entered individually. The individual addition of CARS Score (χ^2 = 4.24, p = .048) yielded a significant improvement in fit when compared with the baseline model. The individual addition of Chronological Age (*p* = .867) Receptive Language (*p* = .223), Expressive Language (*p* = .365), Fine Motor Skills (*p* = .274), and Non-verbal Intelligence (*p* = .212) did not improve fit.

Models 8-12 individually added each of the five fixed effects alongside CARS Score. None of these models significantly improved fit in comparison to Model 7 (+ Chronological Age: *p* = .415; + Receptive Language: *p* = .315; + Expressive Language: *p* = .414; + Fine Motor Skills: *p* = .262; + Non-verbal Intelligence: *p* = .237). These comparisons show that Model 7 is the current best fitting model. Therefore, Model 7 provides the best fit to the observed data.

0–3 trials. We began with a baseline model containing by-participant and by-item random intercepts. Fixed effects of Chronological Age (Model 2), Receptive Language (Model 3), Expressive Language (Model 4), Fine Motor Skills (Model 5), Non-verbal Intelligence (Model 6), and CARS Score (Model 7) were entered individually. The individual addition of Chronological (χ^2 = 18.74, *p* = .001), Receptive Language (χ^2 = 7.75, *p* = .101), Expressive Language (χ^2 = 14.00, *p* < .001), Fine Motor Skills (χ^2 = 17.37, *p* < .001), and Non-verbal Intelligence (χ^2 = 7.09, *p* = .008) yielded significant improvements in fit when compared with the baseline model. The addition of CARS Score (*p* = .173) did not improve fit.

Model 8 included all five of the fixed effects that individually improved predictive fit in comparison to the baseline model: Chronological Age, Receptive Language, Expressive Language, Fine Motor Skills, and Non-verbal Intelligence. The collective addition of these five fixed effects yielded significant or borderline significant improvements in fit in comparison to Model 2 (χ^2 = 18.74, *p* = .001), Model 4 (χ^2 = 8.80, *p* = .066), and Model 6 (χ^2 = 15.71, *p* = .003). Adding the five fixed effects in Model 8 did not significantly improve fit in comparison to Model 3 (*p* = .101) and Model 5 (*p* = .246). These comparisons show that Model 3 and Model 5 are the current joint best fitting models.

Model 9 included Receptive Language and Fine Motor Skills. The inclusion of these two fixed effects yielded a significant improvement in fit in comparison to Model 3 (χ^2 = 4.39, *p* = .036), but did not differ from Model 5 (*p* = .150). This indicates that Model 5 is the current best fitting model.

Models 10–13 individually added each of the other four individually significant fixed effects alongside Fine Motor Skills. Adding Chronological Age (Model 10; *p* = .914), Expressive Language (Model 11; *p* = .083), Non-verbal Intelligence (Model 12; *p* = .336), and CARS Score (Model 13; *p* = .084) did not significantly improve fit in comparison to Model 5. These comparisons show that Model 5 provides the best fit to the observed data.

Social Communication

Response to Name. We began with a model containing Response to Name as the dependent variable with the five remaining social communication measures as predictive effects. Response to Joint Attention (*t* = 3.59, *p* = .002) and Social Smile (*t* = 2.42, *p* = .025) were statistically significant. Initiation of Joint Attention (*p* = .458), Eye Contact (*p* = .434), and Giving (*p* = .187) were not significant.

Model 2 included both of the significant fixed effects: Response to Joint Attention and Social Smile. Omitting the three non-significant effects did not significantly reduce fit in comparison to Model 1 (*p* = .512), which indicates that it is the current best fitting model.

Fixed effects of Chronological Age (Model 3), Receptive Language (Model 4), Expressive Language (Model 5), Fine Motor Skills (Model 6), Non-verbal Intelligence (Model 7), and CARS Score (Model 8) were entered individually alongside the fixed effects included in Model 2. The inclusion of Receptive Language in Model 4 (*F* = 4.34, *p* = .049) and Expressive Language in Model 5 (*F* = 5.06, *p* = .034) yielded significant improvements in predictive fit over Model 2. Models including Chronological Age (*p* = .146), Fine Motor Skills (*p* = .081), Non-verbal Intelligence (*p* = .211), and CARS Score (*p* = .440) did not significantly differ in fit when compared with Model 2. These comparisons show that Model 4 and Model 5 are the current joint best fitting models.

Model 9 contained four predictive effects: Response to Joint Attention, Social Smile, Receptive Language, and Expressive Language. Model 9 did not significantly differ in predictive fit when compared to Model 4 (*p* = .353) or Model 5 (*p* = .582). Model 5 was taken as the final model, because it had a higher R^2 value (0.62) compared to Model 4 (0.61), $F(3, 23) = 15.16$, $p < .001$, adjusted $R^2 = 0.62$. However, it is noteworthy that receptive language and expressive language were highly correlated ($R = 0.82$, $p < .001$), suggesting a predictive effect of children's general language ability encompassing both comprehension and production skills. Response to Joint Attention ($\beta = 0.91$ $p < .001$), Social Smile ($\beta = 0.45$, $p = .003$), and Expressive Language ($\beta = -0.02$, $p = .034$) were significant predictors.

Response to Joint Attention. We began with a model containing Response to Joint Attention as the dependent variable with the five remaining social communication measures as predictive effects. Response to Name ($t = 3.59$, $p = .002$) was statistically significant. Social Smile (*p* = .675), Eye Contact (*p* = .423), Giving (*p* = .324), and Initiation of Joint Attention (*p* = .126) were not significant.

Model 2 included Response to Name, as this was the only fixed effect that significantly improved predictive fit. Omitting the four non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (*p* = .515), which indicates that it is the current best fitting model.

Fixed effects of Chronological Age (Model 3), Receptive Language (Model 4), Expressive Language (Model 5), Fine Motor Skills (Model 6), Non-verbal Intelligence (Model 7), and CARS Score (Model 8) were entered individually alongside Response to

Name. Response to Joint Attention was significantly predicted by Receptive Language (t = 4.90; p = .037) and Expressive Language (t = 11.82; p = .002). The effect of Fine Motor Skills (t = 3.73; p = .065) approached significance. Predictive effects of Chronological Age (p = .406), Non-verbal Intelligence (p = .238), and CARS Score (p = .405) were not significant.

Model 9 contained three predictive effects: Response to Name, Receptive Language, and Expressive Language. Adding both language measures as predictive effects significantly improved predictive fit in comparison to Model 4 (t = 5.97, p = .023) and Model 6 (t = 7.19, p = .013), but did not significantly improve fit in comparison to Model 5 (p = .548). Model 10 contained Response to Joint Attention as the dependent variable with three predictive effects: Response to Name, Receptive Language, and Fine Motor Skills. Including both these measures as predictive effects did not significantly improve fit in comparison to Model 4 (p = .652), Model 5 (p = 1.00) or Model 6 (p = .288). Model 11 contained Response to Joint Attention as the dependent variable with three predictive effects: Response to Name, Expressive Language and Fine Motor Skills. Including both these measures as predictive effects significantly improved predictive fit in comparison to Model 4 (t = 5.51, p = .028), and Model 6 (t = 6.71, p = .016), but did not significantly improve fit in comparison to Model 5 (p = 1.00). These comparisons indicate that Model 5 is the current best fitting model.

Model 12 contained four predictive effects: Response to Name, Receptive Language, Expressive Language, and Fine Motor Skills. Including all four measures as predictive effects did not improve predictive fit in comparison to Model 5 (p = .784), so Model 5 was taken as the final model. Therefore, Response to Joint Attention was best predicted by Model 5, F(2, 24) = 22.06, p < .001, adjusted R^2 = 0.62 (see Table 2). Response to Name (β = 0.44, p < .001) and Expressive Language (β = 0.02, p = .002) were both significant predictors.

Social Smile. We began with a model containing Social Smile as the dependent variable with the five remaining social communication measures as predictive effects. Response to Name (t = 2.42, p = .025) was statistically significant and Initiation of Joint Attention (t = 2.00, p = .059) approached significance. Response to Joint Attention (p = .675), Eye Contact (p = .583), and Giving (p = .830) were not significant.

Model 2 included Response to Name and Initiation of Joint Attention, as these were the only fixed effects that approached or yielded significant improvements in predictive fit. Omitting the three non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (p = .933), which indicates that it is the current best fitting model.

Fixed effects of Chronological Age (Model 3), Receptive Language (Model 4), Expressive Language (Model 5), Fine Motor Skills (Model 6), Non-verbal Intelligence (Model 7), and CARS Score (Model 8) were entered individually alongside the fixed effects included in Model 2. Social Smile was significantly predicted by Chronological Age (t = 15.72, p = .001), and Fine Motor Skills (t = 5.98, p = .023). Predictive effects of Non-verbal Intelligence (t = 4.11, p = .054) and Receptive Language (t = 3.79, p = .064) approached significance. Predictive effects of Expressive Language (p = .111) and CARS Score (p = .965) were not significant.

Given the number of variables that were identified as individually significant predictors, our next sequence of models attempted to identify whether any could be omitted without significantly decreasing predictive fit. We began by adding the factors identified as individually significant, or approaching significance, in pairs alongside the fixed effects included in Model 2. The model that added both Chronological Age and Fine Motor Skills (Model 9) significantly improved predictive fit in comparison to Model 4 (F = 11.05, p = .003), Model 6 (F = 8.55, p = .008), and Model 7 (F = 10.66, p = .004), but did not significantly improve fit in comparison to Model 3 (p = .362). The model that added both

Chronological Age and Receptive Language (Model 10) significantly improved predictive fit in comparison to Model 4 (t = 10.01, p = .004), Model 6 (t = 7.60, p = .012), and Model 7 (t = 9.64, p = .005), but did not significantly improve fit in comparison to Model 3 (p = .702). The model that added both Chronological Age and Non-verbal Intelligence (Model 11) significantly improved predictive fit in comparison to Model 4 (t = 10.00, p = .005), Model 6 (t = 7.59, p = .012), and Model 7 (t = 9.63, p = .005), but did not significantly improve fit in comparison to Model 3 (p = .709). The model that added both Receptive Language and Fine Motor Skills (Model 12) did not significantly improve fit in comparison to Model 3 (p = 1.00), Model 4 (p = .185), Model 6 (p = .794) and Model 7 (p = .220). The model that added both Receptive Language and Non-verbal Intelligence (Model 13) did not significantly improve fit in comparison to Model 3 (p = 1.00), Model 4 (p = .368), Model 6 (p = 1.00), and Model 7 (p = .455). The model that added both Fine Motor Skills and Non-verbal Intelligence (Model 14) did not significantly improve fit in comparison to Model 3 (p = 1.00), Model 4 (p = .189), Model 6 (p = .845), and Model 7 (p = .225). These comparisons indicate that Model 3 is the current best fitting model.

Next, we added the two individually significant demographic variables (Chronological Age and Fine Motor Skills) with one of the marginally significant demographic variables. Adding Receptive Language (Model 15) did not significantly improve fit in comparison to Model 3 (p = .636). Adding Non-verbal Intelligence (Model 16) did not significantly improve fit in comparison to Model 3 (p = .606). These comparisons indicate that Model 3 is the current best fitting model.

Examination of the effects in Model 3 showed that Response to Name and Chronological Age were significant, while Initiation of Joint Attention was not significant. Omitting Initiation of Joint Attention as a fixed effect (Model 19) did not significantly reduce fit in comparison to Model 3 (p = .205). Therefore, Social Smile was best predicted by Model

17, $F(2, 24) = 23.16$, $p < .001$, adjusted $R^2 = 0.63$. Response to Name ($\beta = 0.45$, $p = .001$) and Chronological Age ($\beta = 0.02$, $p < .001$) were both significant predictors.

Eye Contact. We began with a model containing Eye Contact as the dependent variable with the five remaining social communication measures as predictive effects. Initiation of Joint Attention ($t = 1.91$, $p = .070$) approached significance. Response to Joint Attention ($p = .423$), Social Smile ($p = .583$), Response to Name ($p = .434$), and Giving ($p = .345$) were not significant.

Model 2 included Initiation of Joint Attention, as this was the only fixed effect that approached significance. Omitting the four non-significant effects did not significantly improve predictive fit in comparison to Model 1 ($p = .807$), which indicates that it is the current best fitting model.

Fixed effects of Chronological Age (Model 3), Receptive Language (Model 4), Expressive Language (Model 5), Fine Motor Skills (Model 6), Non-verbal Intelligence (Model 7), and CARS Score (Model 8) were entered individually alongside Initiation of Joint Attention. Eye Contact was significantly predicted by Chronological Age ($t = 8.13$, $p = .009$) and CARS Score ($t = 5.25$, $p = .031$). Predictive effects of Receptive Language ($p = .322$), Expressive Language ($p = .967$), Fine Motor Skills ($p = .303$), and Non-verbal Intelligence ($p = .531$) were not significant. These comparisons show that Model 3 and Model 8 are the current joint best fitting models.

Model 9 contained three predictive effects: Initiation of Joint Attention, Chronological Age, and CARS Score. Including these measures as predictive effects significantly improved predictive fit in comparison to Model 8 ($t = 4.64$, $p = 042$), but did not differ in fit in comparison to Model 3 ($p = .155$). Therefore, Eye Contact was best predicted by Model 3, $F(2, 24) = 6.32$, $p = .006$, adjusted $R^2 = 0.29$. Initiation of Joint Attention ($\beta = 0.33$ $p = .006$) and Chronological Age ($\beta = -0.01$, $p = .009$) were significant predictors.

Giving. We began with a model containing Giving as the dependent variable with the five remaining social communication measures as predictive effects. Response to Joint Attention (p = .324), Social Smile (p = .830), Response to Name (p = .187), Eye Contact (p = .345), and Initiation of Joint Attention (p = .484) were not significant.

Fixed effects of Chronological Age (Model 2), Receptive Language (Model 3), Expressive Language (Model 4), Fine Motor Skills (Model 5), Non-verbal Intelligence (Model 6), and CARS Score (Model 7) were entered individually alongside Giving. Predictive effects of Chronological Age (p = .780), Receptive Language (p = .761), Expressive Language (p = .839), Fine Motor Skills (p = .447), Non-verbal Intelligence (p = .188), and CARS Score (p = 899) were not significant. Therefore, Giving was not predicted by any of the social skills or individual differences across participants.

Initiation of Joint Attention. We began with a model containing Initiation of Joint Attention as the dependent variable with the five remaining social communication measures as predictive effects. Social Smile (t = 2.00, p = .059) and Eye Contact (t = 1.91, p = .070) approached significance. Giving (p = .484), Response to Name (p = .458), and Response to Joint Attention (p = .126) were not significant.

Model 2 included Social Smile and Eye Contact, as these were the only fixed effects that approached significant improvements in predictive fit. Omitting the three non-significant effects did not significantly reduce predictive fit in comparison to Model 1 (p = .933), which indicates that it is the current best fitting model. However, examination of the effects in Model 2 showed that Social Smile was significant, while Eye Contact was not significant. Our next step was then to individually remove each of these fixed effects in Models 3 and 4. Removing Eye Contact (Model 3) did not significantly reduce predictive fit in comparison to Model 2 (p = .082). Removing Social Smile (Model 4) significantly reduced predictive fit in comparison to Model 2 ($F = 8.35$, $p = .008$). These comparisons indicate that Model 3 is the current best fitting model.

Fixed effects of Chronological Age (Model 5), Receptive Language (Model 6), Expressive Language (Model 7), Fine Motor Skills (Model 8), Non-verbal Intelligence (Model 9), and CARS Score (Model 10) were entered individually alongside the fixed effects included in Model 3. Predictive effects of Chronological Age ($p = .908$), Receptive Language ($p = .885$), Expressive Language ($p = .871$), Fine Motor Skills ($p = .422$), Non-verbal Intelligence ($p = .461$), and CARS Score ($p = .212$) were not significant. Therefore, Initiation of Joint Attention was best predicted by Model 3, $F(1, 25) = 8.79$, $p = .007$, adjusted $R^2 = 0.23$. Social Smile ($\beta = 0.32$, $p = .007$) was a significant predictor.

Study 2: Examining Interrelations Between Domains, ASD Only

Picture Comprehension

We began with a baseline model containing the variables that were identified as significant in the preceding analyses for this task: Trial Type, Fine Motor Skills, and CARS Score. Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Production (Model 4 = Total Score; Modelled Trials = Model 5; Model 6 = Unmodelled Trials), Social Communication (Model 7 = Total Score; Model 8 = Response to Name; Model 9 = Response to Joint Attention; Model 10 = Social Smile; Model 11 = Eye Contact; Model 12 = Giving; Model 13 = Initiation of Joint Attention), and Independent Drawing (Model 14) were entered individually alongside Trial Type, Fine Motor Skills, and CARS Score. The individual addition of Free Play ($\chi^2 = 6.87$, $p = .009$) and Unmodelled Trials ($\chi^2 = 3.90$, $p = .048$) yielded significant improvements in fit when compared with the baseline model. The addition of Birthday Party ($p = .385$), Picture Production (Total Score: $p = .077$; Modelled Trials: $p = .241$), Social Communication (Total Score: $p = .499$; Response to Name: $p = .120$; Response to Joint Attention: p = .751; Social Smile: p = .434; Eye Contact: p = .503; Giving: p = .424; Initiation of Joint Attention: p = .193), and Independent Drawing (p = .513) did not improve fit.

Model 15 added both of the significant predictors alongside Trial Type, Fine Motor Skills, and CARS Score. The collective addition of Free Play and Unmodelled Trials yielded a significant improvement in fit when compared with Model 6 (χ^2 = 6.42, p = .011), and approached a significant improvement in fit when compared with Model 2 (χ^2 = 3.46, p = .063). These comparisons indicate that Model 15 is the current best fitting model.

Models 17-25 individually added each of the non-significant predictors alongside Trial Type, Fine Motor Skills, CARS Score, Free Play, and Unmodelled Trials. None of these models differed significantly from Model 15 (+ Birthday Party: p = .630; + Modelled Trials: p = .763; + Social Communication: p = .198; + Response to Joint Attention: p = .319; + Social Smile: p = .117; + Eye Contact: p = .394; + Giving: p = .557; + Initiation of Joint Attention: p = .878; + Independent Drawing: p = .459). These comparisons show that Model 15, containing Trial Type, Fine Motor Skills, CARS Score, Free Play, and Unmodelled Trials as fixed effects, provides the best fit to our observed data.

Picture Production

We began with a baseline model containing the variables that were identified as significant in the preceding analyses of individual differences for this task: Trial Type and Fine Motor Skills. Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4 = Total Score; Same Labels Trials = Model 5; Model 6 = Contrasting Labels Trials), Social Communication (Model 7 = Raw Score; Model 8 = Response to Name; Model 9 = Response to Joint Attention; Model 10 = Social Smile; Model 11 = Eye Contact; Model 12 = Giving; Model 13 = Initiation of Joint Attention), and Independent Drawing (Model 14) were entered individually alongside Non-verbal

Intelligence. The individual addition of Free Play (*p* = .736), Birthday Party (*p* = .122), Picture Comprehension (Total Score: *p* = .786; Same Labels Trials: *p* = .740; Contrasting Labels Trials: *p* = .839), Social Communication (Raw Score: *p* = .670; Response to Name: *p* = .643; Response to Joint Attention: *p* = .408; Social Smile: *p* = .782; Eye Contact: *p* = .193; Giving: *p* = .087; Initiation of Joint Attention: *p* = .881), and Independent Drawing (*p* = .215) did not improve fit. These comparisons show that the baseline model, containing Trial Type and Fine Motor Skills as fixed effects, provides the best fit to our observed data.

Total Toys. We began with a baseline model containing Highest Level of Play alongside Total Toys, as this was the only predictive effect that was identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. The inclusion of Modelled Trials in Model 6 (*F* = 3.53, *p* = .072) approached a significant improvement in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: *p* = .202; + Same Labels Trials: *p* = .717; + Contrasting Labels Trials: *p* = .096; + Picture Production: *p* = .202; + Unmodelled Trials: *p* = .589; + Independent Drawing: *p* = .200; + Social Communication: *p* = .335; + Response to Name: *p* = .248; + Response to Joint Attention: *p* = .298; + Social Smile: *p* = .484; + Eye Contact: *p* = .697; + Giving: *p* = .331; + Initiation of Joint Attention: *p* = .716).

Model 6 was taken as the final best-fitting model for Total Toys, $F(2, 24) = 17.86$, $p < .001$, adjusted $R^2 = 0.56$ (see Table 1). Highest Level of Play ($\beta = 1.58$ $p < .001$) was a significant predictor. Modelled Trials ($\beta = 0.32$, $p = .072$) approached significance.

Highest Level of Play. We began with a baseline model containing Total Toys and Uses Toys as Agents alongside Highest Level of Play, as both of these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. The inclusion of Social Smile in Model 12 ($F = 3.59$, $p = .071$) and Giving in Model 14 ($F = 4.07$, $p = .055$) approached significant improvements in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: $p = .513$; + Same Labels Trials: $p = .394$; + Contrasting Labels Trials: $p = .266$; + Modelled Trials: $p = .968$; Unmodelled Trials: $p = .231$; + Independent Drawing: $p = .990$; + Social Communication: $p = .283$; + Response to Name: $p = .581$; + Response to Joint Attention: $p = .720$; + Eye Contact: $p = .324$; + Initiation of Joint Attention: $p = .590$). These comparisons show that Model 12 and Model 14 are the current joint best fitting models.

Model 16 contained Social Smile and Giving alongside the predictive effects in the baseline model. Adding both of these borderline significant effects in Model 16 did not significantly improve fit in comparison to Model 12 ($p = .075$) or Model 14 ($p = .096$).

Model 14 was taken as the final model as its adjusted R^2 value (0.673) was fractionally higher than Model 12 (0.666), $F(3, 23) = 18.81$, $p < .001$, adjusted $R^2 = 0.67$. Total Toys, ($\beta = 0.20$ $p = .003$), Uses Toys as Agents ($\beta = 0.70$ $p = .003$), and Giving ($\beta = 0.54$ $p = .055$) were significant predictors.

Uses Toys as Agents. We began with a baseline model containing Total Toys, Highest Level of Play, and Object Substitution, as these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. None of the models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: $p = .480$; + Same Labels Trials: $p = .782$; + Contrasting Labels Trials: $p = .462$; + Picture Production: $p = .939$; + Modelled Trials: $p = .806$; Unmodelled Trials: $p = .691$; + Independent Drawing: $p = .694$; + Social Communication: $p = .234$; + Response to Name: $p = .394$; + Response to Joint Attention: $p = .760$; + Social Smile: $p = .087$; + Eye Contact: $p = .928$; + Giving: $p = .278$; + Initiation of Joint Attention: $p = .516$), so the baseline model was taken as the final model.

Object Substitution. We began with a baseline model containing Uses Toys as Agents and Adult Intervention Required, as these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model

6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. None of the models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: $p = .773$; + Same Labels Trials: $p = .810$; + Contrasting Labels Trials: $p = .801$; + Picture Production: $p = .290$; + Modelled Trials: $p = .161$; Unmodelled Trials: $p = .584$; + Independent Drawing: $p = .146$; + Social Communication: $p = .903$; + Response to Name: $p = .862$; + Response to Joint Attention: $p = .944$; + Social Smile: $p = .768$; + Eye Contact: $p = .167$; + Giving: $p = .185$; + Initiation of Joint Attention: $p = .589$), so the baseline model was taken as the final model

Unusual Sensory Interest. We began with a baseline model containing Chronological Age alongside Total Toys, as this was the only predictive effect that was identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. The inclusion of Response to Name in Model 10 ($F = 3.78$, $p = .064$) approached a significant improvement in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Picture Comprehension: $p = .834$; + Same Labels Trials: $p = .610$; + Contrasting Labels Trials: $p = .950$; + Picture Production: $p = .440$; + Modelled Trials: $p = .301$; + Unmodelled Trials: $p =$

.755; + Independent Drawing: p = .507; + Social Communication: p = .089; + Response to Joint Attention: p = .815; + Social Smile: p = .097; + Eye Contact: p = .655; + Giving: p = .241; + Initiation of Joint Attention: p = .254).

Model 10 was taken as the final best-fitting model for Unusual Sensory Interest, F(2, 24) = 6.44, p = .006, adjusted R^2 = 0.30. Chronological Age (β = -0.01 p = .028) was a significant predictor. Response to Name (β = -0.18, p = .064) approached significance.

Adult Intervention Required. We began with a baseline model containing Chronological Age and Non-verbal Intelligence, as these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. The inclusion of Picture Comprehension (Model 2; F = 5.92, p = .023) and Contrasting Labels Trials (Model 4; F = 4.97, p = .036) yielded a significant improvement in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Same Labels Trials: p = .109; + Picture Production: p = .785; + Modelled Trials: p = .868; Unmodelled Trials: p = .488; + Independent Drawing: p = .699; + Social Communication: p = .835; + Response to Name: p = .418; + Response to Joint Attention: p = .993; + Social Smile: p = .942; + Eye Contact: p = .756; + Giving: p = .655; + Initiation of Joint Attention: p = .617). These comparisons show that Models 2 and 4 are the current best fitting models.

As Picture Comprehension was a composite score that captured performance on both Same and Contrasting Labels Trials, and the former was not an individually significant predictor, its predictive effect appears to be driven by the Contrasting Labels Trials. Consequently, Model 4 was taken as the final best-fitting model for Adult Intervention Required, $F(3, 23) = 5.66$, $p = .005$, adjusted $R^2 = 0.35$. Chronological Age ($\beta = -0.01$, $p = .002$), Non-verbal Intelligence ($\beta = 0.02$, $p = .005$), and Contrasting Labels Trials ($\beta = -0.13$, $p = .036$) were significant predictors.

Imitates Modelled Play. We began with a baseline model containing Highest Level of Play, as this was the only predictive effect that was identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Picture Comprehension (Model 2), Same Labels Trials (Model 3), Contrasting Labels Trials (Model 4), Picture Production (Model 5), Modelled Trials (Model 6), Unmodelled Trials (Model 7), Independent Drawing (Model 8), Social Communication (Model 9), Response to Name (Model 10), Response to Joint Attention (Model 11), Social Smile (Model 12), Eye Contact (Model 13), Giving (Model 14), and Initiation of Joint Attention (Model 15) were entered individually alongside the fixed effects included in the baseline model. The models that individually added Picture Comprehension (Model 2; $F = 7.91$, $p = .010$), Same Labels Trials (Model 3; $F = 5.65$, $p = .026$), Contrasting Labels Trials (Model 4; $F = 5.57$, $p = .027$), Response to Name (Model 10; $F = 4.01$, $p = .057$), and Eye Contact (Model 13; $F = 5.72$, $p = .025$) yielded significant or borderline significant improvements in predictive fit over the baseline model. None of the other models significantly differed in fit when compared with the baseline model (+ Picture Production: $p = .354$; + Modelled Trials: $p = .127$; + Unmodelled Trials: $p = .871$; + Independent Drawing: $p = .533$; + Social Communication: $p = .608$; + Response to Joint Attention: $p = .955$; +

Social Smile: p = .661; + Giving: p = .409; + Initiation of Joint Attention: p = .671). These comparisons show that Models 2, 3, 4, 10, and 13 are the current best fitting models.

Model 16 contained Picture Comprehension, Response to Name, and Eye Contact alongside the predictive effects in the baseline model. Same Labels Trials and Contrasting Labels Trials were not included in this model, as Picture Comprehension was a composite score that captured performance on both trial types, and all three of these were individually significant predictors. Adding these three significant and borderline significant effects in Model 16 significantly improved fit in comparison to Model 2 (F = 5.65, p = .010), 3 (F = 6.92, p = .005), Model 4 (F = 6.97, p = .005), Model 10 (F = 7.97, p = .002), or Model 13 (F = 6.87, p = .005). These comparisons show that Model 16 is the current best fitting model.

Models 17-19 individually removed each of the three significant or borderline significant predictive effects contained in Model 16. The models that individually removed Picture Comprehension (Model 17; F = 4.72 p = .041), Response to Name (Model 18; F = 3.92 p = .060), and Eye Contact (Model 19; F = 9.25, p = .006) significantly reduced fit compared to Model 16.

Model 16 was taken as the final best-fitting model for Imitates Modelled Play, F(4, 22) = 8.95, p < .001, adjusted R^2 = 0.55. Highest Level of Play (β = -0.41 p = .002), Picture Comprehension (β = -0.11 p = .004), Response to Name (β = 0.15, p = .060), and Eye Contact (β = -0.56 p = .006) were significant or borderline significant predictors.

Birthday Party

0–1 trials. We began with a baseline model containing CARS Score, as this was the only variable that was identified as significant in the preceding analyses for this task, plus by-participant and by-item random intercepts. Fixed effects of Free Play (Model 2), Picture Comprehension (Model 3), Same Labels Trials (Model 4), Contrasting Labels Trials (Model 5), Picture Production (Model 6), Modelled Trials (Model 7), Unmodelled Trials (Model 8), Independent Drawing (Model 9), Social Communication (Model 10), Response to Name (Model 11), Response to Joint Attention (Model 12), Social Smile (Model 13), Eye Contact (Model 14), Giving (Model 15), and Initiation of Joint Attention (Model 16) were entered individually alongside CARS Score. None of these models improved fit when compared with the baseline model (+ Free Play: p = .789; + Picture Comprehension: p = .119; + Same Labels Trials: p = .371; + Contrasting Labels Trials: p = .129; + Picture Production: p = .943; + Modelled Trials: p = .399; + Unmodelled Trials: p = .486; + Independent Drawing: p = .148; + Social Communication: p = .447; + Response to Name: p = .534; + Response to Joint Attention: p = .956; + Social Smile: p = .660; + Eye Contact: p = .129; + Giving: p = .400; + Initiation of Joint Attention: p = .153), so the baseline model provides the best fit to our observed data.

0–3 trials. We began with a baseline model containing Fine Motor Skills, as this was the only variable that was identified as significant in the preceding analyses for this task, plus by-participant and by-item random intercepts. Fixed effects of Free Play (Model 2), Picture Comprehension (Model 3), Same Labels Trials (Model 4), Contrasting Labels Trials (Model 5), Picture Production (Model 6), Modelled Trials (Model 7), Unmodelled Trials (Model 8), Independent Drawing (Model 9), Social Communication (Model 10), Response to Name (Model 11), Response to Joint Attention (Model 12), Social Smile (Model 13), Eye Contact (Model 14), Giving (Model 15), and Initiation of Joint Attention (Model 16) were entered individually alongside CARS Score. The individual addition of Free Play (χ^2 = 7.86, p = .005) and Eye Contact (χ^2 = 4.86, p = .027) yielded significant improvements in fit when compared with the baseline model. The addition of Picture Comprehension (p = .195), Same Labels Trials (p = .271), Contrasting Labels Trials (p = .254), Picture Production (p = .848), Modelled Trials (p = .605), Unmodelled Trials (p = .392), Independent Drawing (p = .383), Social Communication (p = .306), Response to Name (p = .980), Response to Joint Attention

(p = .252), Social Smile (p = .695), Giving (p = .670), and Initiation of Joint Attention (p = .138) did not improve fit.

Model 17 added both of the significant predictors alongside Fine Motor Skills. The addition of Free Play and Eye Contact yielded a significant improvement in fit when compared with Model 2 (χ^2 = 5.72, p = .017) and Model 14 (χ^2 = 8.71, p = .003). These comparisons show that Model 17 provides the best fit to our observed data.

Social Communication

Response to Name. We began with a baseline model containing Response to Joint Attention, Social Smile, and Expressive Language, as these three predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4), Same Labels Trials (Model 5), Contrasting Labels Trials (Model 6), Picture Production (Model 7), Modelled Trials (Model 8), Unmodelled Trials (Model 9), and Independent Drawing (Model 10) were entered individually alongside the fixed effects included in the baseline model. None of these models significantly differed in fit when compared with the baseline model (+ Free Play: p = .457; + Birthday Party: p = .432; + Picture Comprehension: p = .091; + Same Labels Trials: p = .229; + Contrasting Labels Trials: p = .121; Picture Production: p = .589; + Modelled Trials: p = .564; + Unmodelled Trials: p = .689; + Independent Drawing: p = .937), so the baseline model was taken as the final model.

Response to Joint Attention. We began with a baseline model containing Response to Name and Expressive Language, as both of these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4), Same Labels Trials (Model 5), Contrasting Labels Trials (Model

6), Picture Production (Model 7), Modelled Trials (Model 8), Unmodelled Trials (Model 9), and Independent Drawing (Model 10) were entered individually alongside the fixed effects included in the baseline model. None of the models significantly differed in fit when compared with the baseline model (+ Free Play: p = .488; + Birthday Party: p = .688; + Picture Comprehension: p = .467; + Same Labels Trials: p = .338; + Contrasting Labels Trials: p = .621; Picture Production: p = .598; + Modelled Trials: p = .529; + Unmodelled Trials: p = .757; + Independent Drawing: p = .554), so the baseline model was taken as the final model.

Social Smile. We began with a baseline model containing Response to Name and Chronological Age, as both of these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4), Same Labels Trials (Model 5), Contrasting Labels Trials (Model 6), Picture Production (Model 7), Modelled Trials (Model 8), Unmodelled Trials (Model 9), and Independent Drawing (Model 10) were entered individually alongside the fixed effects included in the baseline model. None of these models significantly differed in fit when compared with the baseline model (+ Free Play: p = .657; + Birthday Party: p = .302; + Picture Comprehension: p = .940; + Same Labels Trials: p = .511; + Contrasting Labels Trials: p = .874; Picture Production: p = .255; + Modelled Trials: p = .219; + Unmodelled Trials: p = .441; + Independent Drawing: p = .255), so the baseline model was taken as the final model.

Eye Contact. We began with a baseline model containing Initiation of Joint Attention and Chronological Age alongside Eye Contact, as both of these predictive effects were identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4), Same Labels Trials (Model 5), Contrasting Labels Trials (Model 6), Picture Production (Model 7), Modelled Trials (Model 8), Unmodelled Trials (Model 9), and Independent Drawing (Model 10) were entered individually alongside the fixed effects included in the baseline model. None of these models significantly differed in fit when compared with the baseline model (+ Free Play: p = .527; + Birthday Party: p = .103; + Picture Comprehension: p = .632; + Same Labels Trials: p = .712; + Contrasting Labels Trials: p = .473; Picture Production: p = .374; + Modelled Trials: p = .105; + Unmodelled Trials: p = .941; + Independent Drawing: p = .299), so the baseline model was taken as the final model.

Giving. As there were no predictive effects identified as significant in the preceding analyses of individual differences for this task, fixed effects of Free Play (Model 1), Birthday Party (Model 2), Picture Comprehension (Model 3), Same Labels Trials (Model 4), Contrasting Labels Trials (Model 5), Picture Production (Model 6), Modelled Trials (Model 7), Unmodelled Trials (Model 8), and Independent Drawing (Model 9) were entered individually alongside Giving. Predictive effects of Free Play (p = .920), Birthday Party (p = .314), Picture Comprehension (p = .715), Same Labels Trials (p = .452), Contrasting Labels Trials (p = .872), Picture Production (p = .653), Modelled Trials (p = .480), Unmodelled Trials (p = .903), and Independent Drawing (p = .439) were not significant. Therefore, Giving was not predicted by social communication, play or pictorial skills across participants.

Initiation of Joint Attention. We began with a baseline model containing Social Smile, as this predictive effect was identified as significant in the preceding analyses of individual differences for this task.

Fixed effects of Free Play (Model 2), Birthday Party (Model 3), Picture Comprehension (Model 4), Same Labels Trials (Model 5), Contrasting Labels Trials (Model

6), Picture Production (Model 7), Modelled Trials (Model 8), Unmodelled Trials (Model 9), and Independent Drawing (Model 10) were entered individually alongside the fixed effects included in the baseline model. None of these models significantly differed in fit when compared with the baseline model (+ Free Play: p = .250; + Birthday Party: p = .304; + Picture Comprehension: p = .664; + Same Labels Trials: p = .301; + Contrasting Labels Trials: p = .882; Picture Production: p = .567; + Modelled Trials: p = .742; + Unmodelled Trials: p = .466; + Independent Drawing: p = .401), so the baseline model was taken as the final model.

Study 3: Predicting Accuracy from Population, Trial Type, Individual Differences, and Pictures, Play and Social Communication, Matched Subsets

Picture Comprehension

We began with a baseline model containing by-participant and by-item random intercepts. Adding Population as a fixed effect (Model 2) did not improve fit in comparison to the baseline model (p = .976). To explore whether the effects of variables differed between neurotypical children and autistic children, Models 3-23 included an individual Population x [factor] interaction. Individual interactions between Population and Trial Type (Model 4; p = .112), CARS Score (Model 6; p = .332), Trial Number (Model 7; p = .851), Receptive Language (Model 9; p = .134), Expressive Language (Model 10; p = .184), Free Play (Model 11; p = .078), Birthday Party (Model 12; p = .117), Social Communication (Model 13; p = .937), Response to Name (Model 14; p = .392), Response to Joint Attention (Model 15; p = .990), Social Smile (Model 16; p = .901), Eye Contact (Model 17; p = .996), Giving (Model 18; p = .918), and Initiation of Joint Attention (Model 19; p = .077) were non-significant. The individual addition of Population x Modelled Trials (Model 21; χ^2 = 7.37, p = .061) approached significance. The individual addition of Population x Non-verbal Intelligence

(Model 3; χ^2 = 15.30, p = .002), Fine Motor Skills (Model 5; χ^2 = 9.52, p = .023), Chronological Age (Model 8; χ^2 = 8.35, p = .039), Picture Production (Model 20; χ^2 = 9.23, p = .026), Unmodelled Trials (Model 22; χ^2 = 8.82, p = .032), and Independent Drawing (Model 23; χ^2 = 9.42, p = .024) yielded significant improvements in fit when compared with the baseline model.

Examining the significance of the individual effects in Models 3, 5, 8, 20, 21, 22, and 23 revealed that only the Population x Non-verbal Intelligence (Z = 1.95, p = .051) and Population x Chronological Age (Z = -2.23, p = .026) interactions approached or exceeded the threshold for statistical significance. All other interactions were non-significant (x Trial Type: p = .819; x Fine Motor Skills: p = .849; x CARS Score: p = .999; x Trial Number: p = .943; x Receptive Language: p = .628; x Expressive Language: p = .980; x Free Play: p = .260; x Birthday Party: p = .031; x Social Communication: p = .523; x Response to Name: p = .301; x Response to Joint Attention: p = .946; x Social Smile: p = .705; x Eye Contact: p = .844; x Giving: p = .969; x Initiation of Joint Attention: p = .991; x Picture Production: p = .616; x Modelled Trials: p = .911; x Unmodelled Trials: p = .478; x Independent Drawing: p = .653), indicating that improvements in model fit over the baseline were due to the addition of a fixed effect that did not differ between populations.

Next, we created a model containing both of the significant interactions. Model 24 (Population x Non-verbal Intelligence + Population x Chronological Age) significantly differed in fit when compared with Model 8 (χ^2 = 8.43; p = .015), but not Model 3 (p = .479). These comparisons show that Model 3 provides the best fit to the observed data.

Picture Production

We began with a baseline model containing by-participant and by-item random intercepts. Adding Population as a fixed effect (Model 2) did not improve fit in comparison to the baseline model (p = .919). To explore whether the effects of variables differed between neurotypical children and autistic children, Models 3-23 included an individual Population x [factor] interaction. Models including interactions between Population and Trial Number (Model 6; p = .291), CARS Score (Model 10; p = .802), Free Play (Model 11; p = 139), Social Communication (Model 13; p = .230), Response to Name (Model 14; p = .528), Response to Joint Attention (Model 15; p = .255), Social Smile (Model 16; p = .525), Eye Contact (Model 17; p = .987), Initiation of Joint Attention (Model 19; p = .294), Same Labels Trials (Model 21; p = .176), and Contrasting Labels Trials (Model 22; p = .125) did not significantly differ in fit when compared with the baseline model. The individual addition of Population x Picture Comprehension (Model 20; χ^2 = 7.41, p = .060) yielded a borderline-significant improvement in fit in comparison to the baseline model. The individual addition of Population x Trial Type (Model 3; 15.07, p = .002), Chronological Age (Model 4; 18.16, p < .001), Fine Motor Skills (Model 5; 43.06, p < .001), Receptive Language (Model 7; 16.82, p = .001), Expressive Language (Model 8; 17.11, p = .001), Non-verbal Intelligence (Model 9; χ^2 = 16.13, p = .001), Birthday Party (Model 12; 10.17, p = .017), Giving (Model 18; 11.92, p = .008), and Independent Drawing (Model 23; 13.63, p = .003) yielded significant improvements in fit when compared with the baseline model.

Examining the significance of the individual effects in Models 3, 4, 5, 7, 8, 9, 12, 18, 20, and 23 revealed that only the Population x Chronological Age (Model 4: Z = -2.83, p = .005) and Population x Giving (Model 18: Z = -3.13, p = .002) interactions were significant. All other interaction effects were non-significant (x Trial Type: p = .532; x Fine Motor Skills: p = .149; x CARS Score: p = .349; x Trial Number: p = .071; x Receptive Language: p = .271; x Expressive Language: p = .090; x Free Play: p = .162; x Birthday Party: p = .276; x Social Communication: p = .352; x Response to Name: p = .351; x Response to Joint Attention: p = .937; x Social Smile: p = .310; x Eye Contact: p = .718; x Initiation of Joint Attention: p = .176; x Picture Comprehension: p = .108; x Same Labels Trials: p = .166; x

Contrasting Labels Trials: $p = .128$; x Independent Drawing: $p = .093$), indicating that improvements in model fit over the baseline were due to the addition of a fixed effect that did not differ between populations.

Next, we created a model containing both of the significant interactions. Model 24 (Population x Chronological Age + Population x Giving) significantly differed in fit when compared with Model 4 ($\chi^2 = 13.73$; $p = .001$) and Model 18 ($\chi^2 = 19.96$; $p < .001$). These comparisons show that Model 24 provides the best fit to the observed data.

Free Play

Total Toys. We began by testing whether Total Toys was predicted by Population. The model was significant, $F = 17.72$, $p < .001$.

To explore whether predictive effects differed between neurotypical children and autistic children, Models 2-22 included an individual Population x [factor] interaction. Models including interactions between Population x Expressive Language (Model 4; $p = .109$), x CARS Score (Model 7; $p = .327$), x Birthday Party (Model 8; $p = .085$), x Response to Name (Model 10; $p = .289$), x Response to Joint Attention (Model 11; $p = .115$), x Social Smile (Model 12; $p = .224$), x Giving (Model 14; $p = .186$), x Initiation of Joint Attention (Model 15; $p = .271$), and x Same Labels Trials (Model 17; $p = .312$) did not significantly differ in fit when compared with Model 1, containing only a fixed effect of Population. The models that individually included Population x Chronological Age (Model 2; $F = 2.82$, $p = .069$), x Receptive Language (Model 3; $F = 2.94$, $p = .062$), x Fine Motor Skills (Model 5; $F = 4.98$, $p = .011$), Non-verbal Intelligence (Model 6; $F = 6.19$, $p = .004$), x Social Communication (Model 9; $F = 4.23$, $p = .020$), x Eye Contact (Model 13; $F = 3.21$, $p = .049$), x Picture Comprehension (Model 16; $F = 4.91$, $p = .011$), x Contrasting Labels Trials (Model 18; $F = 7.36$, $p = .002$) x Picture Production (Model 19; $F = 6.15$, $p = .004$), x Modelled Trials (Model 20; $F = 5.04$, $p = .010$), x Unmodelled Trials (Model 21; $F = 4.84$, $p = .012$), and x Independent Drawing (Model 22; *F* = 3.91, *p* = .026) yielded significant or borderline significant improvements in fit when compared with Model 1.

Examining the significance of the individual effects in Models 2, 3, 5, 6, 9, 13, 16, 18, 19, 20, 21, and 22 revealed that only the Population x Non-verbal Intelligence (*t* = -2.48, *p* = .017), x Eye Contact (*t* = -2.01, *p* = .050), and x Contrasting Labels Trials (*t* = -2.34, *p* = .023) interactions approached or exceeded the threshold for statistical significance. All other interactions were non-significant (x Chronological Age: *p* = .201; x Receptive Language: *p* = .446; x Expressive Language: *p* = .174; x Fine Motor Skills: *p* = .421; x CARS Score: *p* = .150; x Birthday Party: *p* = .088; x Social Communication: *p* = .283; x Response to Name: *p* = 700; x Response to Joint Attention: *p* = .641; x Social Smile: *p* = .694; x Giving: *p* = .281; x Initiation of Joint Attention: *p* = .943; x Picture Comprehension: *p* = .241; x Same Labels Trials: *p* = .312; x Picture Production: *p* = .407; x Modelled Trials: *p* = .472; x Unmodelled Trials: *p* = .472; x Independent Drawing: *p* = .227), indicating that improvements in model fit over the baseline were due to the addition of a fixed effect that did not differ between populations.

Next, we created a model containing the three significant interactions. Model 23 (Population x Non-verbal Intelligence + Population x Eye Contact + Population x Contrasting Labels Trials) yielded or approached significant improvements in fit when compared with Model 6 (*F* = 3.06; *p* = .026), Model 13 (*F* = 4.60; *p* = .003), and Model 18 (*F* = 2.54; *p* = .053). These comparisons show that Model 23 is the current best fitting model.

Models 24-26 individually removed each of the significant Population x [factor] interactions included in Model 23. The models that individually removed Population x Non-verbal Intelligence (Model 24; *p* = .214) and x Eye Contact (Model 26; *p* = .104) did not significantly reduce fit when compared with Model 23. The model that individually removed Population x Contrasting Labels Trials (Model 25; *F* = 3.48, *p* = .039) was significantly worse fitting when compared with Model 23. These comparisons show that Model 24 and Model 26 are the current joint best fitting models. Model 24 was taken as the final model as its adjusted R^2 value (0.44) was higher than that of Model 26 (0.42), indicating that it captured more variability in the dependent measure, $F(5, 48) = 9.42$, $p < .001$, adjusted R^2 = 0.44.

Highest Level of Play. We began by testing whether Highest Level of Play was predicted by Population. The model was significant, $F = 14.20$, $p < .001$.

To explore whether predictive effects differed between neurotypical children and autistic children, Models 2-22 included an individual Population x [factor] interaction. Models including interactions between Population x Chronological Age (Model 2; $p = .201$), x Receptive Language (Model 3; $p = .506$), x Expressive Language (Model 4; $p = .587$), x Fine Motor Skills (Model 5; $p = .540$), Non-verbal Intelligence (Model 6; $p = .488$), x CARS Score (Model 7; $p = .542$), x Response to Name (Model 10; $p = .205$), x Response to Joint Attention (Model 11; $p = .345$), x Eye Contact (Model 13; $p = .298$), x Giving (Model 14; $p = .292$), x Initiation of Joint Attention (Model 15; $p = .231$), x Picture Comprehension (Model 16; $p = .266$), x Same Labels Trials (Model 17; $p = .192$), x Contrasting Labels Trials (Model 18; $p = .259$), x Picture Production (Model 19; $p = .083$), x Modelled Trials (Model 20; $p = .281$), and x Independent Drawing (Model 22; $p = .907$) did not significantly differ in fit when compared with Model 1, containing only a fixed effect of Population. The models that individually included Population x Birthday Party (Model 8; $F = 3.78$, $p = .030$), x Social Communication (Model 9; $F = 4.04$, $p = .024$), x Social Smile (Model 12; $F = 4.25$, $p = .020$), and x Unmodelled Trials (Model 21; $F = 3.45$, $p = .039$) yielded significant or borderline significant improvements in fit when compared with Model 1.

Examining the significance of the individual effects in Models 8, 9, 12 and 21 22 revealed that none of these Population x [factor] interactions were significant (x

Chronological Age: *p* = .752; x Receptive Language: *p* = .818; x Expressive Language: *p* = .734; x Fine Motor Skills: *p* = .953; x Non-verbal Intelligence: *p* = .323; x CARS Score: *p* = .374; x Birthday Party: *p* = .105; x Social Communication: *p* = .514; x Response to Name: *p* = .387; x Response to Joint Attention: *p* = .747; x Social Smile: *p* = .932; x Eye Contact: *p* = .132; x Giving: *p* = .989; x Initiation of Joint Attention: *p* = .415; x Picture Comprehension: *p* = .892; x Same Labels Trials: *p* = .172; x Contrasting Labels Trials: *p* = .461; x Picture Production: *p* = .920; x Modelled Trials: *p* = .803; x Unmodelled Trials: *p* = .608; x Independent Drawing: *p* = .756), indicating that improvements in model fit over the baseline were due to the addition of a fixed effect that did not differ between populations. Therefore, Highest Level of Play was best predicted by Model 1.

Uses Toys as Agents. We began by testing whether Uses Toys as Agents was predicted by Population. The model was significant, *F* = 10.63, *p* = .002.

To explore whether predictive effects differed between neurotypical children and autistic children, Models 2-22 included an individual Population x [factor] interaction. Models including interactions between Population x Chronological Age (Model 2; *p* = .677), Receptive Language (Model 3; *p* = .434), Expressive Language (Model 4; *p* = .197), x Fine Motor Skills (Model 5; *p* = .198), Non-verbal Intelligence (Model 6; *p* = .495), x CARS Score (Model 7; *p* = .128), x Birthday Party (Model 8; *p* = .208), x Response to Name (Model 10; *p* = .289), x Response to Joint Attention (Model 11; *p* = .258), x Social Smile (Model 12; *p* = .340), x Eye Contact (Model 13; *p* = .500), x Initiation of Joint Attention (Model 15; *p* = .271), x Picture Comprehension (Model 16; *p* = .256), x Same Labels Trials (Model 17; *p* = .409), x Contrasting Labels Trials (Model 18; *p* = .213), and x Independent Drawing (Model 22; *p* = .461) did not significantly differ in fit when compared with Model 1, containing only a fixed effect of Population. The models that individually included Population x Social Communication (Model 9; *F* = 3.53, *p* = .037), x Giving (Model 14; *F* = 2.97, *p* = .060), x

Picture Production (Model 19; F = 4.27, p = .019), x Modelled Trials (Model 20; F = 2.86, p = .066), x Unmodelled Trials (Model 21; F = 4.21, p = .020), yielded significant or borderline significant improvements in fit when compared with Model 1.

Examining the significance of the individual effects in Models 9, 14, 19, 20, and 21 revealed that only the Population x Social Communication (t = -2.06, p = .045) and x Giving (t = -1.86, p = .068) interactions approached or exceeded the threshold for statistical significance. All other interactions were non-significant (x Chronological Age: p = .387; x Receptive Language: p = .332; x Expressive Language: p = .140; x Fine Motor Skills: p = .110; x Non-verbal Intelligence: p = .495; x CARS Score: p = .111; x Birthday Party: p = .949; x Response to Name: p = .183; x Response to Joint Attention: p = .258; x Social Smile: p = .262; x Eye Contact: p = .430; x Initiation of Joint Attention: p = .940; x Picture Comprehension: p = .572; x Same Labels Trials: p = .235; x Contrasting Labels Trials: p = .745; x Picture Production: p = .077; x Modelled Trials: p = .088; x Unmodelled Trials: p = .152; and x Independent Drawing: p = .216), indicating that improvements in model fit over the baseline were due to the addition of a fixed effect that did not differ between populations.

Next, we created a model containing both of the significant interactions. Model 23 (Population x Social Communication + Population x Giving) did not significantly improve fit when compared with Model 9 (p = .026) or Model 14 (p = .003). These comparisons show that Model 9 and Model 14 are the current joint best fitting models. Model 9 was taken as the final model as its adjusted R^2 value (0.23) was higher than that of Model 14 (0.21), $F(3, 50)$ = 6.25, p =.001, adjusted R^2 = 0.23.

Object Substitution. We began by testing whether Object Substitution was predicted by Population. The model was significant, F = 11.00, p = .002.

To explore whether predictive effects differed between neurotypical children and autistic children, Models 2-22 included an individual Population x [factor] interaction.

Models including interactions between Population x Chronological Age (Model 2; p = .955), Receptive Language (Model 3; p = .278), Expressive Language (Model 4; p = .375), x Fine Motor Skills (Model 5; p = .297), Non-verbal Intelligence (Model 6; p = .293), x CARS Score (Model 7; p = .883), x Birthday Party (Model 8; p = .496), x Response to Name (Model 10; p = .416), x Response to Joint Attention (Model 11; p = .796), x Social Smile (Model 12; p = .192), x Giving (Model 14; p = .283), x Initiation of Joint Attention (Model 15; p = .186), x Picture Comprehension (Model 16; p = .147), x Same Labels Trials (Model 17; p = .305), x Contrasting Labels Trials (Model 18; p = .181), x Picture Production (Model 19; p = .229), x Modelled Trials (Model 20; p = .131), x Unmodelled Trials (Model 21; p = .444), and x Independent Drawing (Model 22; p = .315) did not significantly differ in fit when compared with Model 1, containing only a fixed effect of Population. The models that individually included Population x Social Communication (Model 9; F = 3.44, p = .040) and x Eye Contact (Model 13; F = 3.21 p = .049) yielded significant or borderline significant improvements in fit when compared with Model 1.

Examining the significance of the individual effects in Models 9 and 13 revealed that only the Population x Social Communication (t = -1.90, p = .063) interaction approached the threshold for statistical significance. All other interactions were non-significant (x Chronological Age: p = .962; x Receptive Language: p = .327; x Expressive Language: p = .266; x Fine Motor Skills: p = .135; x Non-verbal Intelligence: p = .126; x CARS Score: p = .760; x Birthday Party: p = .997; x Response to Name: p = .216; x Response to Joint Attention: p = .801; x Social Smile: p = .223; x Eye Contact: p = .102; x Giving: p = .197; x Initiation of Joint Attention: p = .938; x Picture Comprehension: p = .745; x Same Labels Trials: p = .713; x Contrasting Labels Trials: p = .459; x Picture Production: p = .226; x Modelled Trials: p = .087; x Unmodelled Trials: p = .614; x Independent Drawing: p = .132), indicating that improvements in model fit over the baseline were due to the addition of a fixed effect that did not differ between populations. Therefore, Object Substitution was best predicted by Model 9.

Unusual Sensory Interest. We began by testing whether Unusual Sensory Interest was predicted by Population. The model was significant, $F = 12.87$, $p = .001$.

To explore whether predictive effects differed between neurotypical children and autistic children, Models 2-22 included an individual Population x [factor] interaction. Models including interactions between Population x Receptive Language (Model 3; $p = .486$), Expressive Language (Model 4; $p = .364$), x Fine Motor Skills (Model 5; $p = .845$), Non-verbal Intelligence (Model 6; $p = .127$), x CARS Score (Model 7; $p = .230$), x Birthday Party (Model 8; $p = .970$), x Response to Joint Attention (Model 11; $p = .412$), x Eye Contact (Model 13; $p = .860$), x Giving (Model 14; $p = .282$), x Picture Comprehension (Model 16; $p = .968$), x Same Labels Trials (Model 17; $p = .854$), x Contrasting Labels Trials (Model 18; $p = .828$), x Picture Production (Model 19; $p = .444$), x Modelled Trials (Model 20; $p = .807$), x Unmodelled Trials (Model 21; $p = .232$), and x Independent Drawing (Model 22; $p = .459$) did not significantly differ in fit when compared with Model 1, containing only a fixed effect of Population. The models that individually included Population x Chronological Age (Model 2; $F = 7.08$, $p = .002$), x Social Communication (Model 9; $F = 6.81$, $p = .002$), x Response to Name (Model 10; $F = 5.30$, $p = .008$), x Social Smile (Model 12; $F = 9.84$, $p < .001$), and x Initiation of Joint Attention (Model 15; $F = 3.39$, $p = .042$) yielded significant or borderline significant improvements in fit when compared with Model 1.

Examining the significance of the individual effects in Models 2, 9, 10, 12, and 15 revealed that only the Population x Social Smile ($t = -2.04$, $p = .047$) interaction was significant. All other interactions were non-significant (x Chronological Age: $p = .753$; x Receptive Language: $p = .817$; x Expressive Language: $p = .768$; x Fine Motor Skills: $p = .701$; x Non-verbal Intelligence: $p = .617$; x CARS Score: $p = .126$; x Birthday Party: $p =$

.912; x Social Communication: p = .103; x Response to Name: p = .186; x Response to Joint Attention: p = .309; x Eye Contact: p = .833; x Giving: p = .237; x Initiation of Joint Attention: p = .102; x Picture Comprehension: p = .956; x Same Labels Trials: p = .730; x Contrasting Labels Trials: p = .892; x Picture Production: p = .442; x Modelled Trials: p = .642; x Unmodelled Trials: p = .318; x Independent Drawing: p = .258), indicating that improvements in model fit over the baseline were due to the addition of a fixed effect that did not differ between populations. Therefore, Unusual Sensory Interest was best predicted by Model 12.

Adult Intervention Required. We began by testing whether Adult Intervention Required was predicted by Population. The model was significant, F = 8.97, p = .004.

To explore whether predictive effects differed between neurotypical children and autistic children, Models 2-22 included an individual Population x [factor] interaction. Models including interactions between Population x Chronological Age (Model 2; p = .239), Receptive Language (Model 3; p = .123), Expressive Language (Model 4; p = .174), x Fine Motor Skills (Model 5; p = .754), Non-verbal Intelligence (Model 6; p = .768), x CARS Score (Model 7; p = .842), x Response to Name (Model 10; p = .468), x Response to Joint Attention (Model 11; p = .495), x Giving (Model 14; p = .141), x Initiation of Joint Attention (Model 15; p = .144), x Picture Comprehension (Model 16; p = .415), x Same Labels Trials (Model 17; p = .485), x Contrasting Labels Trials (Model 18; p = .490), x Picture Production (Model 19; p = .203), x Modelled Trials (Model 20; p = .288), x Unmodelled Trials (Model 21; p = .230), and x Independent Drawing (Model 22; p = .940) did not significantly differ in fit when compared with Model 1, containing only a fixed effect of Population. The models that individually included Population x Birthday Party (Model 8; F = 4.05, p = .023), x Social Communication (Model 9; F = 7.02, p = .002), x Social Smile (Model 12; F = 6.71, p =

.003), and x Eye Contact (Model 13; $F = 3.15$, $p = .051$) yielded significant or borderline significant improvements in fit when compared with Model 1.

Examining the significance of the individual effects in Models 8, 9, 12 and 13 revealed that only the Population x Social Communication ($t = 2.58$, $p = .013$) and x Eye Contact ($t = 0.36$, $p = .022$) were significant. All other interactions were non-significant (x Chronological Age: $p = .534$; x Receptive Language: $p = .374$; x Expressive Language: $p = .229$; x Fine Motor Skills: $p = .522$; x Non-verbal Intelligence: $p = .547$; x CARS Score: $p = .774$; x Birthday Party: $p = .162$; x Response to Name: $p = .249$; x Response to Joint Attention: $p = .491$; x Social Smile: $p = .088$; x Giving: $p = .965$; x Initiation of Joint Attention: $p = .832$; x Picture Comprehension: $p = .365$; x Same Labels Trials: $p = .741$; x Contrasting Labels Trials: $p = .760$; x Picture Production: $p = .473$; x Modelled Trials: $p = .391$; x Unmodelled Trials: $p = .676$; and x Independent Drawing: $p = .909$), indicating that improvements in model fit over the baseline were due to the addition of a fixed effect that did not differ between populations.

Next, we created a model containing both of the significant interactions. Model 23 (Population x Social Communication + Population x Eye Contact) did not significantly improve fit when compared with Model 9 ($p = .198$) or Model 13 ($p = .156$). These comparisons show that Model 9 and Model 13 are the current joint best fitting models. Model 9 was taken as the final model as its adjusted R^2 value (0.29) was higher than that of Model 13 (0.20), $F(3, 50) = 8.36$, $p < .001$, adjusted $R^2 = 0.29$.

Imitates Modelled Play. We began by testing whether Imitates Modelled Play was predicted by Population. The model was not significant ($p = .389$).

Models 2-22 tested the Population x [factor] interactions. Individual interactions between Population x Chronological Age (Model 2; $p = .552$), Receptive Language (Model 3; $p = .840$), Expressive Language (Model 4; $p = .503$), x Fine Motor Skills (Model 5; $p = .708$), Non-verbal Intelligence (Model 6; *p* = .790), x CARS Score (Model 7; *p* = .235), x Birthday Party (Model 8; *p* = .131), x Social Communication (Model 9; *p* = .432), x Response to Name (Model 10; *p* = .464), x Response to Joint Attention (Model 11; *p* = .800), x Social Smile (Model 12; *p* = .331), x Eye Contact (Model 13; *p* = .097), x Giving (Model 14; *p* = .758), x Initiation of Joint Attention (Model 15; *p* = .308), x Contrasting Labels Trials (Model 18; *p* = .077), x Picture Production (Model 19; *p* = .777), x Modelled Trials (Model 20; *p* = .516), x Unmodelled Trials (Model 21; *p* = .707), and x Independent Drawing (Model 22; *p* = .747) were not significant. The models that individually included Population x Picture Comprehension (Model 16; *F* = 3.45, *p* = .023) and x Same Labels Trials (Model 17; *F* = 3.12 *p* = .034) were significant.

Examining the significance of the individual effects in Models 16 and 17 revealed that only the Population x Same Labels Trials (*t* = -1.90, *p* = .063) approached significance. All other interactions were non-significant (x Chronological Age: *p* = .253; x Receptive Language: *p* = .933; x Expressive Language: *p* = .395; x Fine Motor Skills: *p* = .456; x Non-verbal Intelligence: *p* = .925; x CARS Score: *p* = .162; x Birthday Party: *p* = .761; x Social Communication: *p* = .340; x Response to Name: *p* = .963; x Response to Joint Attention: *p* = .717; x Social Smile: *p* = .423; x Eye Contact: *p* = .950; x Giving: *p* = .535; x Initiation of Joint Attention: *p* = .912; x Picture Comprehension: *p* = .101; x Contrasting Labels Trials: *p* = .292; x Picture Production: *p* = .763; x Modelled Trials: *p* = .851; x Unmodelled Trials: *p* = .438; x Independent Drawing: *p* = .847), indicating that these models were significant due to the inclusion of a fixed effect that did not differ between populations. Therefore, Imitates Modelled Play was best predicted by Model 17.

Birthday Party

0–1 trials. We began with a baseline model containing by-participant and by-item random intercepts. All models originally included random effects of Participant and Trial

Type, however, some models failed to converge. Therefore, the random effects structure was simplified by omitting Trial Type for all models in this particular analysis and only including Participant.

Adding Population as a fixed effect (Model 2) did not improve fit in comparison to the baseline model (p = .161). To explore whether the effects of variables differed between neurotypical children and autistic children, Models 3-22 included an individual Population x [factor] interaction. Individual interactions between Population and Chronological Age (Model 3; p = .090), Receptive Language (Model 4; p = .434), Expressive Language (Model 5; p = .441), Fine Motor Skills (Model 6; p = .451), Non-verbal Intelligence (Model 7; p = .319), CARS Score (Model 8; p = .177), Social Communication (Model 9; p = .191), Response to Name (Model 10; p = .385), Response to Joint Attention (Model 11; p = .451), Social Smile (Model 12; p = .229), Eye Contact (Model 13; p = .204), Giving (Model 14; p = .243), Initiation of Joint Attention (Model 15; p = .233), Picture Comprehension (Model 16; p = .093), Same Labels Trials (Model 17; p = .129), Contrasting Labels Trials (Model 18; p = .165), Picture Production (Model 19; p = .533), Modelled Trials (Model 20; p = .429), Unmodelled Trials (Model 21; p = .526), Independent Drawing (Model 22; p = .449), and Free Play (Model 23; p = .093) were not significant when compared with the baseline model. Therefore, the baseline model provided the best fit to our observed data, indicating performance on 0–1 trials was not predicted by population, individual differences, play, pictures, or social communication.

0–3 trials. We began with a baseline model containing by-participant and by-item random intercepts. All models originally included random effects of Participant and Trial Type, however, some models failed to converge. Therefore, the random effects structure was simplified by omitting Trial Type for all models in this particular analysis and only including Participant.

Adding Population as a fixed effect (Model 2) significantly improved fit in comparison to the baseline model ($\chi^2 = 18.99$, $p < .001$). To explore whether the effects of variables differed between neurotypical children and autistic children, Models 3-23 included an individual Population x [factor] interaction. Models including interactions between Population and CARS Score (Model 8; $p = .197$), Social Communication (Model 9; $p = .087$), Response to Name (Model 10; $p = .717$), Eye Contact (Model 13; $p = .456$), Giving (Model 14; $p = .187$), Initiation of Joint Attention (Model 15; $p = .248$), and Same Labels Trials (Model 17; $p = .425$) did not significantly differ in fit when compared with Model 2. The individual addition of Population x Chronological Age (Model 3; $\chi^2 = 5.34$, $p = .069$), Modelled Trials (Model 20; $\chi^2 = 5.83$, $p = .054$), Independent Drawing (Model 22; $\chi^2 = 5.52$, $p = .063$), and Free Play (Model 23; $\chi^2 = 5.47$, $p = .065$) yielded a borderline-significant improvement in fit in comparison to Model 2. The individual addition of Population x Receptive Language (Model 4; $\chi^2 = 22.20$, $p < .001$), Expressive Language (Model 5; $\chi^2 = 17.68$, $p < .001$), Fine Motor Skills (Model 6; $\chi^2 = 18.51$, $p < .001$), Non-verbal Intelligence (Model 7; $\chi^2 = 9.89$, $p = .007$), Response to Joint Attention (Model 11; $\chi^2 = 6.64$, $p = .036$), Social Smile (Model 12; $\chi^2 = 7.49$, $p = .024$), Picture Comprehension (Model 16; $\chi^2 = 7.10$, $p = .029$), Contrasting Labels Trials (Model 18; $\chi^2 = 8.70$, $p = .013$), Picture Production (Model 19; $\chi^2 = 9.60$, $p = .008$), and Unmodelled Trials (Model 21; $\chi^2 = 10.87$, $p = .004$) yielded significant improvements in fit when compared with Model 2.

Examining the significance of the individual effects in Models 3, 4, 5, 6, 7, 11, 12, 16, 18, 19, 20, 21, 22, and 23 revealed that the Population x Fine Motor ($Z = 2.53$, $p = .012$), x Non-verbal Intelligence ($Z = 2.30$, $p = .023$), x Response to Joint Attention ($Z = 2.09$, $p = .038$), x Picture Comprehension ($Z = 2.27$, $p = .024$), x Contrasting Labels Trials ($Z = 2.54$, $p = .012$), x Unmodelled Trials ($Z = 1.86$, $p = .065$), and x Free Play ($Z = 1.94$, $p = .053$) interactions were significant or borderline significant. All other interactions were non-significant (x Chronological Age: p = .951; x Receptive Language: p = .582; x Expressive Language: p = .362; x CARS Score: p = .126; x Social Communication: p = .639; x Response to Name: p = .499; x Social Smile: p = .867; x Eye Contact: p = .267; x Giving: p = .097; x Initiation of Joint Attention: p = .316; x Same Labels Trials: p = .257; x Picture Production: p = .141; x Modelled Trials: p = .367; and x Independent Drawing: p = .230), indicating that improvements in model fit over Model 2 were due to the addition of a fixed effect that did not differ between populations.

Next, we created a model containing six of the significant interactions. As Picture Comprehension was a composite score that captured performance on both Same and Contrasting Labels Trials, and the former did not yield a significant interaction, Picture Comprehension was not included in this model. Model 24 (Population x Fine Motor + Population x Non-verbal Intelligence + Population x Response to Joint Attention + Population x Contrasting Labels Trials + Population x Unmodelled Trials + Population x Free Play) significantly improved fit when compared with Model 7 (χ^2 = 22.74, p = .012), Model 11 (χ^2 = 25.99, p = .004), Model 18 (χ^2 = 23.93, p = .008), Model 21 (χ^2 = 21.76, p = .016), and Model 23 (χ^2 = 27.17, p = .002), but did not significantly differ from Model 6 (p = .168). These comparisons show that Model 6 is the current best fitting model.

Models 25-29 individually added each of the five significant interactions alongside Population x Fine Motor. The individual addition of Population x Free Play (Model 29; χ^2 = 6.58, p = .037) significantly improved fit when compared with Model 6. None of the other models significantly improved fit when compared with Model 6 (+ Population x Non-verbal Intelligence: p = .190; + Population x Response to Joint Attention: p = .387; + Population x Contrasting Labels Trials: p = .085; + Population x Unmodelled Trials: p = .577). These comparisons show that Model 29 is the current best fitting model.

Models 30–33 individually added each of the four significant interactions alongside the effects included in Model 29. None of these models significantly improved fit when compared with Model 29 (+ Population x Non-verbal Intelligence: p = .205; + Population x Response to Joint Attention: p = .577; + Population x Contrasting Labels Trials: p = .133; + Population x Unmodelled Trials: p = .775). These comparisons show that Model 29 provides the best fit to the observed data.

Social Communication

Response to Name. We began by testing whether Response to Name was predicted by Population. The model was significant, F = 13.11, p = .001.

To explore whether predictive effects differed between neurotypical children and autistic children, Models 2-16 included an individual Population x [factor] interaction. Models including interactions between Population x Chronological Age (Model 2; p = .163), x Receptive Language (Model 3; p = .772), x Expressive Language (Model 4; p = .187), x Fine Motor Skills (Model 5; p = .486), Non-verbal Intelligence (Model 6; p = .763), CARS Score (Model 7; p = .499), x Free Play (Model 8; p = .615), x Birthday Party (Model 9; p = .479), x Picture Comprehension (Model 10; p = .143), x Same Labels Trials (Model 11; p = .224), x Contrasting Labels Trials (Model 12; p = .209), x Picture Production (Model 13; p = .473), x Modelled Trials (Model 14; p = .489), x Unmodelled Trials (Model 15; p = .500), and x Independent Drawing (Model 16; p = .898) did not significantly differ in fit when compared with Model 1, containing only a fixed effect of Population. Therefore, Response to Name was best predicted by Model 1.

Social Smile. We began by testing whether Social Smile was predicted by Population. The model was significant, F = 19.63, p < .001.

To explore whether the effects of variables differed between neurotypical children and autistic children, Models 2-16 included an individual Population x [factor] interaction.

Individual interactions between Population x Non-verbal Intelligence (Model 6; *p* = .159), x CARS Score (Model 7; *p* = .590), x Free Play (Model 8; *p* = .111), x Picture Comprehension (Model 10; *p* = .725), x Same Labels Trials (Model 11; *p* = .442), x Contrasting Labels Trials (Model 12; *p* = .917), x Picture Production (Model 13; *p* = .301), x Modelled Trials (Model 14; *p* = .541), x Unmodelled Trials (Model 15; *p* = .212), and x Independent Drawing (Model 16; *p* = .269) did not significantly differ in fit when compared with Model 1, containing only a fixed effect of Population. The models that individually included Population x Receptive Language (Model 3; *F* = 2.74, *p* = .074), x Expressive Language (Model 4; *F* = 3.00, *p* = .059), and x Fine Motor Skills (Model 5; *F* = 3.04, *p* = .057) approached significance. The models that individually included Population x Chronological Age (Model 2; *F* = 11.31, *p* < .001), and x Birthday Party (Model 9; *F* = 5.51, *p* = .007) yielded significant improvements in fit when compared with Model 1.

Examining the significance of the individual effects in Models 2, 3, 4, 5, and 9 revealed that only the Population x Chronological Age (*t* = 2.94, *p* = .005) and Population x Fine Motor Skills (*t* = 1.92, *p* = .060) interactions approached or exceeded the threshold for statistical significance. All other interactions were non-significant (x Non-verbal Intelligence: *p* = .349; x CARS Score: *p* = .410; x Free Play: *p* = .111; x Birthday Party: *p* = .851; x Picture Comprehension: *p* = .700; x Same Labels Trials: *p* = .725; Contrasting Labels Trials: *p* = .301; Picture Production: *p* = .243; Modelled Trials: *p* = .362; x Unmodelled Trials: *p* = .206; x Independent Drawing: *p* = .108), indicating that improvements in model fit over the baseline were due to the addition of a fixed effect that did not differ between populations.

Next, we created a model containing both of the significant interactions. Model 17 (Population x Chronological Age + Population x Fine Motor Skills) significantly differed in fit when compared with Model 5 (*F* = 7.61; *p* = .001), but not Model 2 (*p* = .668). These comparisons show that Model 2 provides the best fit to the observed data.

Eye Contact. We began by testing whether Eye Contact was predicted by Population. The model was significant, *F* = 63.41, *p* < .001.

To explore whether the effects of variables differed between neurotypical children and autistic children, Models 2-16 included an individual Population x [factor] interaction. Individual interactions between Population x Chronological Age (Model 2; *p* = .099), x Receptive Language (Model 3; *p* = .728), x Expressive Language (Model 4; *p* = .652), x Fine Motor Skills (Model 5; *p* = 644), x Non-verbal Intelligence (Model 6; *p* = .857), x CARS Score (Model 7; *p* = .143), x Free Play (Model 8; *p* = .206), x Birthday Party (Model 9; *p* = .422), x Picture Comprehension (Model 10; *p* = .971), x Same Labels Trials (Model 11; *p* = .833), x Contrasting Labels Trials (Model 12; *p* = .918), x Picture Production (Model 13; *p* = .290), x Modelled Trials (Model 14; *p* = .091), and x Unmodelled Trials (Model 15; *p* = .758), did not significantly differ in fit when compared with Model 1, containing only a fixed effect of Population. The model that individually added Independent Drawing (Model 16; *F* = 3.16, *p* = .051) approached significance.

Examining the significance of the individual effects in Model 16 revealed that the Population x Independent Drawing (*p* = .138) was not significant. All other interactions were non-significant (x Chronological Age: *p* = .365; x Receptive Language: *p* = .462; x Expressive Language: *p* = .635; x Fine Motor Skills: *p* = .763; x Non-verbal Intelligence: *p* = .708; x CARS Score: *p* = .553; x Free Play: *p* = .164; x Birthday Party: *p* = .466; x Picture Comprehension: *p* = .809; x Same Labels Trials: *p* = .842; Contrasting Labels Trials: *p* = .861; Picture Production: *p* = .291; Modelled Trials: *p* = .116; x Unmodelled Trials: *p* = .698), indicating that improvements in model fit over the baseline were due to the addition of a fixed effect that did not differ between populations. Therefore, Eye Contact was best predicted by Model 1.

Giving. We began by testing whether Giving was predicted by Population. The model was not significant (p = .130).

Models 2-16 tested the Population x [factor] interactions. Individual interactions between Population x Chronological Age (Model 2; p = .387), x Receptive Language (Model 3; p = .286), x Expressive Language (Model 4; p = .261), x Fine Motor Skills (Model 5; p = .080), x Non-verbal Intelligence (Model 6; p = .357), x CARS Score (Model 7; p = .477), x Picture Comprehension (Model 10; p = .380), x Same Labels Trials (Model 11; p = .274), and x Contrasting Labels Trials (Model 12; p = .501) were not significant. The models that individually included Population x Free Play (Model 8; F = 2.74, p = .053) and x Independent Drawing (Model 16; F = 2.46, p = .074) approached significance. The models that individually included Population x Birthday Party (Model 9; F = 3.11, p = .034), x Picture Production (Model 13; F = 4.08, p = .011), x Modelled Trials (Model 14; F = 3.26, p = .029), and x Unmodelled Trials (Model 15; F = 3.65, p = .019) were significant.

Examining the significance of the individual effects in Models 8, 9, 13, 14, 15, and 16 revealed that the x Birthday Party (t = -2.41 p = .020), x Picture Production (t = -2.38 p = .021), x Modelled Trials (t = -2.24 p = .029), x Unmodelled Trials (t = -2.01 p = .050) interactions approached or exceeded the threshold for statistical significance. All other interactions were non-significant (x Chronological Age: p = .436, x Receptive Language: p = .265, x Expressive Language: p = .308, x Non-verbal Intelligence: p = .730; x CARS Score: p = .691; x Free Play: p = .082; x Picture Comprehension: p = .604; x Same Labels Trials: p = .881; Contrasting Labels Trials: p = .823; x Independent Drawing: p = .335), indicating that these models were significant due to the inclusion of a fixed effect that did not differ between populations.

Model 17 contained three significant interactions (Population x Fine Motor Skills + Population x Birthday Party + Population x Picture Production). Modelled Trials and

Unmodelled Trials were not included in this model, because Picture Production was a composite score that captured performance on both trial types. Model 17 approached a significant improvement in fit when compared with Model 5 ($F = 2.36$; $p = .067$), but not Model 9 ($p = .136$) or Model 13 ($p = .312$). Models 18-20 each contained two significant interactions. Model 18 (Population x Birthday Party + Population x Picture Production) significantly improved fit when compared with Model 5 ($F = 4.86$, $p = .012$), and Model 9 ($F = 3.80$, $p = .029$), but not Model 13 ($p = .092$). Model 19 (Population x Fine Motor Skills + Population x Picture Production) did not significantly improve fit when compared with Model 5 ($p = .106$), Model 9 ($p = .260$), or Model 13 ($p = .813$). Model 20 (Population x Fine Motor Skills + Population x Birthday Party) approached a significant improvement in fit when compared with Model 5 ($F = 2.95$, $p = .062$), but not Model 9 ($p = .152$), or Model 13 ($p = .475$). These comparisons show that Model 13 is the current best fitting model. Therefore, Giving was best predicted by Model 13.

Initiation of Joint Attention. We began by testing whether Initiation of Joint Attention was predicted by Population. The model was not significant, $p = 1.00$.

To explore whether the effects of variables differed between neurotypical children and autistic children, Models 2-16 included an individual Population x [factor] interaction. Individual interactions between Population x Chronological Age (Model 2; $p = .229$), x Receptive Language (Model 3; $p = .615$), x Expressive Language (Model 4; $p = .315$), x Fine Motor Skills (Model 5; $p = .214$), x Non-verbal Intelligence (Model 6; $p = .986$), x CARS Score (Model 7; $p = .352$), x Free Play (Model 8; $p = .328$), x Birthday Party (Model 9; $p = .296$), x Picture Comprehension (Model 10; $p = .395$), x Same Labels Trials (Model 11; $p = .847$), x Contrasting Labels Trials (Model 12; $p = .168$), x Picture Production (Model 13; $p = .309$), x Modelled Trials (Model 14; $p = .555$), x Unmodelled Trials (Model 15; $p = .246$), and x Independent Drawing (Model 16, $p = .246$) were not significant.

Therefore, Initiation of Joint Attention was not predicted by any of the social skills or individual differences across participants.