Investigating the relationship between language and picture understanding in children with autism spectrum disorder.

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Abstract

Previous studies report that minimally-verbal children with autism spectrum disorder (ASD) show impaired picture comprehension when matched to typically developing (TD) controls on language comprehension. Here we compare *both* picture comprehension and picture production abilities in linguistically-delayed children with ASD and TD controls matched on language comprehension *and* language production. Participants were 20 children with ASD (*M* age: 11.2 years) and 20 TD children (*M* age: 4.4 years) matched on age equivalents for receptive language (ASD *M*: 4.6 years; TD *M*: 4.5 years) and expressive language (ASD: 4.4 years; TD: 4.5 years). Picture comprehension was assessed by asking children to identify the 3-D referents of line drawings. Picture production was assessed by asking children to create representational drawings of unfamiliar objects and having raters identify their referents. The results of both picture tasks revealed statistically equivalent performance for TD children and children with ASD, and identical patterns of performance across trial types. These findings suggest that early deficits in pictorial understanding displayed by minimally-verbal individuals may diminish as their expressive language skills develop. Theoretically, our study indicates that development in linguistic and pictorial domains may be inter-related for children with ASD (as is the case for typical development).

Keywords: autism spectrum disorder, language, pictures, comprehension, production, symbolic understanding.

Investigating the relationship between language and picture understanding in children with autism spectrum disorder.

If children are to become effective communicators, it is vital that they learn to comprehend and produce a range of symbols (Happé, 1995; Klin, Jones, Schultz, Volkmar & Cohen, 2002; Wetherby, Prizant & Schuler, 2000). However, many children diagnosed with Autism Spectrum Disorder (ASD) show profound deficits in symbolic communication (Jarrold, Boucher, & Smith, 1993; Lord, Risi, & Pickles, 2004; Preissler, 2008). ASD is often characterised by severe impairments in the comprehension and production of language (Anderson et al., 2007; Tager-Flusberg & Kasari, 2013), and recent evidence suggests that minimally-verbal children with ASD also have an atypical understanding of pictures (Hartley & Allen, 2014a, 2014b, 2015a, 2015b; Preissler, 2008). As language scaffolds understanding of pictures in young typically developing (TD) children (Callaghan, 2000; Callaghan & Rankin, 2002; Kirkham, Stewart & Kidd, 2013), it is possible that deficits in these two symbolic domains are related in ASD. By extension, differences in pictorial communication may diminish in children who can effectively use language to support their understanding of visual representations. For the first time, this research investigates whether children with ASD and TD children differ in their comprehension and production of pictures when matched on their comprehension *and* production of language.

In most cultures, infants are immersed in spoken language from birth and caregivers prioritise facilitating their understanding of linguistic representations over all other symbols (Adamson, 1995). Owing to this early and extensive support, linguistic symbols are mastered by TD children earlier and more rapidly than pictorial systems (Nelson, 2007). Importantly, social-cultural theorists argue that symbolic understanding of language is a crucial precursor to understanding picture-referent relations (Callaghan, 1999, 2000, 2008; Callaghan & Rankin, 2002). Once TD children learn that verbal labels refer to objects in the world, they can infer that pictures also relate to independently existing objects when they are named

(Preissler & Bloom, 2007; Hartley & Allen, 2015a). Indeed, TD infants' early decoding of picture-referent relations may be dependent on substituting unfamiliar pictorial symbols for familiar linguistic symbols (Callaghan & Rankin, 2002). This phenomenon was demonstrated by Callaghan (2000; see also Homer & Nelson, 2005), who assessed picture comprehension in TD children aged 2.5 and 3 years under conditions that afforded or inhibited linguistic scaffolding. Children were shown a series of line drawings and were required to identify their referents from pairs of objects. In 'standard trials', the objects had distinct verbal labels (e.g. cat vs. dog), whereas objects in 'control trials' shared the same verbal label (e.g. cat vs. cat). Thus, pictures could be matched to their correct referents via naming in standard trials, but not control trials. The results revealed that above-chance performance in 2.5 year olds was contingent on linguistic scaffolding, whereas 3 year olds performed above-chance in both trial types. These findings have important implications for ASD; deficits in verbal labelling may impact children's understanding of how pictures relate to the world (Hartley & Allen, 2014b, 2015a).

Recent research has demonstrated that minimally-verbal children with ASD have an atypical understanding of symbolic relationships between words, pictures, and objects. In Preissler (2008) and Hartley and Allen (2015a), minimally-verbal children with ASD were taught the names of unfamiliar objects depicted in drawings and photographs. At test, children were asked to identify the referents of the newly-learned words when presented with the pictures and their previously unseen depicted referents. In both studies, the children with ASD displayed a strong tendency to select the picture alone, indicating their failure to understand that the label referred to the symbolised object. Furthermore, Hartley and Allen (2014b) found that minimally-verbal children with ASD frequently extend names from pictures to referent objects based on shape (a category-relevant cue) *or* colour (a category-irrelevant cue). By contrast, TD children matched on language comprehension almost always extend labels to the 3-D referents of pictures (Hartley & Allen, 2015a; Preissler & Carey, 2004), and privilege similarity of shape as basis for mapping word-picture-object relationships (Hartley & Allen, 2014b). Taken together, these studies show that minimally-verbal children with ASD often display atypical symbolic understanding of pictures despite having comparable receptive language skills to TD controls.

As the children with ASD in these studies were minimally-verbal recipients of picture-based communication interventions (e.g. the Picture Exchange Communication System; Bondy & Frost, 1994), it is inevitable that their language production skills were substantially lower than those of TD controls. However, evidence from typical development indicates that expressive language makes an important contribution to normative pictorial development. Both Callaghan and Rankin (2002) and Kirkham et al (2013) reported positive statistical relationships between graphic symbolism skills and language production abilities in TD children aged 3-4 years. As pictures are a cultural convention that are acquired through social interactions (Callaghan et al., 2011; Callaghan, Rochat & Corbit, 2012; Callaghan, Rochat, MacGillivray, & MacLellan, 2004), the ability to talk about visual representations may facilitate children's learning about these symbols. In addition, the development of expressive language influences how TD children process and conceptually organise visual stimuli. Around 2 years, once their expressive vocabulary consists of at least 50 count nouns, TD children selectively attend to global shape when categorising objects (Gershkoff-Stowe & Smith, 2004; Samuelson & Smith, 1999). It is theorised that the process of learning and producing object names directs children to infer that shape determines category membership (Landau et al., 1988). This rule also applies to pictures – the shape of graphic markings usually indicates the symbolised referent – and, by 24-months, TD children categorise them with objects accordingly (Ganea, Allen, Butler, Carey, & DeLoache, 2009). By contrast, language production deficits experienced by children with ASD will diminish their ability to communicate about pictures during early development. Severely restricted productive vocabularies coupled with qualitative differences in visual processing (e.g. weak central coherence; Frith & Happé, 1994) may also inhibit minimally-verbal children with ASD from recognising that shape constrains picture-object relationships. Rather, their processing of pictures may be increasingly feature-based, with individual perceptual details (e.g. shape, colour, size) providing independent bases for mapping depending on their relative salience (Hartley & Allen, 2014b).

If difficulties in pictorial understanding are linked to impairments in language production, it follows that differences between developmentally-delayed children with ASD and TD children may decrease when matched on both expressive and receptive language. The present study is the first to address this possibility in relation to both picture comprehension *and* picture production. It is notable that the aforementioned studies focus exclusively on comprehension. However, to fully assess understanding of a symbol system, it is necessary to measure both comprehension and production. While it is well-documented that TD infants' receptive skills significantly outweigh their productive skills in every communicative domain (Adamson, 1995; Callaghan, 1999; McCune, 1995), many children with ASD do not show the normative advantage for receptive over expressive communication skills (Hudry et al., 2014). We also explore whether variation in children's pictorial understanding is statistically predicted by variation in their concurrent linguistic skills and/or non-verbal IQ. Although previous studies have reported statistical relationships between picture comprehension skills and receptive vocabulary in ASD (Hartley & Allen, 2014b, 2015b), no prior research has explored relationships to language production. In addition, it is highly probable that minimally-verbal children and TD controls matched on receptive vocabulary differ on both non-verbal IQ and language production. Thus, it is currently unclear how non-verbal intellectual functioning contributes to pictorial understanding in ASD, and whether between-population differences on this variable contribute to symbolic understanding.

The objectives of this study were to (1) identify whether the picture comprehension and picture production abilities of linguistically-delayed children with ASD are *equivalent* to those of TD controls when matched on both comprehension and production of language, and (2) identify predictive relationships between pictorial skills and children's concurrent language abilities, non-verbal IQ, and other demographic variables. Picture comprehension was tested using a variation of Callaghan's (2000) paradigm which assesses children's reliance on verbal labelling as a scaffold for picture-object mapping. Picture production was assessed via a graphic symbolism task, which measures children's representational drawing skills under conditions that vary in difficulty (Kirkham et al., 2013). Based on the hypothesis that language production may contribute to pictorial understanding, we predicted that linguistically-delayed children with ASD would not differ from TD controls on pictorial understanding tasks when matched on both language comprehension and production. In both populations, we also expected to observe differences in children's picture comprehension accuracy depending on the accessibility of linguistic scaffolding. Importantly, our findings will advance understanding of both TD and ASD populations by indicating to what extent symbolic comprehension and production skills in the domains of language and pictures relate to each other.

Method

Participants

Participants were 20 children with ASD (19 males, 1 female; *M* age = 11.2 years; *SD* = 2.7 years; range = 7.2–16.1 years) recruited from a specialist school, and 20 TD children (13 males, 7 females; *M* age = 4.4 years; *SD* = 0.5 years; range = 3.4–5.1 years) recruited from a mainstream school and nursery. Children with ASD were previously diagnosed by a qualified educational or clinical psychologist, using standardised instruments (i.e. Autism Diagnostic Observation Scale Version 1 and Autism Diagnostic Interview – Revised; Lord, Rutter, DiLavore & Risi, 2002; Lord, Rutter & Le Couteur, 1994) and expert judgement. Diagnoses were confirmed via the Childhood Autism Rating Scale (CARS; Schopler, Reichler, DeVellis, & Daly, 1980), which was completed by each participant's class teacher

(ASD group: *M* score = 34.85; *SD* = 3.86; range = 30 – 42; TD group: *M* score = 15.2, *SD* = 0.41; range = 15–16.5). Children's language comprehension and language production were measured by the receptive and expressive language modules of the Mullen Scales of Early Learning (Mullen, 1995). The children with ASD had a mean language comprehension age of 4.6 years (*SD* = 1.1 years; range = 2.3–5.8 years) and a mean language production age of 4.4 years (*SD* = 1.3 years; range = 2–5.8 years). The TD children had a mean language comprehension age of 4.5 years (*SD* = 0.5 years; range = 3.5–5.4 years) and a mean language production age of 4.5 years (*SD* = 0.7 years; range = 3–5.8 years). Although every child with ASD had delayed language development relative to their chronological age, groups did not statistically differ on either language comprehension, $t(38) = .55$, $p = .58$, or language production, $t(38) = .35$, $p = .73$. Children's non-verbal intellectual abilities were measured using the Leiter-R (Roid & Miller, 1997). The mean IQ of the ASD group was 68.8 (*SD* = 22.8), indicating that the sample was broadly characterised by additional intellectual difficulties. The mean IQ of the TD group was significantly higher at 108.67 (*SD* = 9.81), $t(38) = 7.18$, $p < .001$. The study was approved by the Lancaster University Ethics Committee and informed consent was obtained from parents.

Materials

Stimuli for the picture comprehension task included 24 objects and 24 black-and-white line drawings of those objects. Sixteen of these objects were highly familiar, and were selected on the basis that most children understand their linguistic labels by 15 months (Fensen et al., 1994).[1] These objects included: teddy bear, spoon, cup, hairbrush, plastic banana, model cow, key, model cat, 2 model cars, 2 plastic bottles, 2 miniature shoes and 2

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[1] The age of acquisition estimations reported in Fensen et al (1994) are based on norms for TD children. We are confident that the children with ASD understood these words because (a) the early vocabularies of autistic children are dominated by concrete nouns (just like TD children; Tager-Flusberg., 1990), (b) receptive vocabulary is a linguistic strength for verbal children with ASD (Mayes & Calhoun, 2003), and (c) our sample's average language comprehension age of 4.6 years accommodates a substantial delay in acquisition for individual words.

model dogs. The other eight objects were unfamiliar, and were selected on the basis that children would not know their linguistic labels. All object stimuli are displayed in Figure 1. Examples of the black-and-white line drawings are shown in Figure 2.

Stimuli for the picture production task included 6 different unfamiliar objects (see Figure 3), pencils and white A5 paper sheets.

Figure 1. Object stimuli used in the Picture Comprehension task. Objects were paired with another object in the same block (1, 2 or 3) during the task

Figure 2. Example black-and-white line drawings used in the Picture Comprehension task

Figure 3. Unfamiliar objects used in the Picture Production task

Procedure

Participants were tested individually in their own schools and were accompanied by a familiar adult. Children were reinforced for attention and good behaviour. In separate sessions, on different days, children completed standardised assessments of language comprehension, language production, and non-verbal intelligence. They also completed experimental tests of picture comprehension and picture production (described below). Order of tasks was randomised for each participant.

Mullen Scales receptive language module (Mullen, 1995). The Mullen Scales is a comprehensive developmental assessment that generates a profile of children's cognitive and motor abilities. This test benefits from very low language demands (it is suitable for children aged < 1 year) and is frequently administered to children with ASD. The receptive language module tests auditory discrimination and auditory/motor integration. Examples include recognition of familiar names and words, identification of objects and pictures, performing simple actions on request, comprehending questions, testing spatial concepts, identification of colours and numbers.

Mullen Scales expressive language module (Mullen, 1995). The Mullen Scales' expressive language module tests overall productive verbal abilities. Examples include 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.

Leiter-R (Roid & Miller, 1997). The Leiter-R is a measure of non-verbal intellectual function that is specifically designed for children with language impairments. The test can be administered without verbal instructions and children's responses generally involve identifying and/or sequencing picture cards or foam shapes. 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 and complete patterns.

Picture comprehension task. Children completed a standard picture-object matching task (Callaghan, 1999; Callaghan, 2000; Callaghan et al., 2011; Callaghan, Rochat & Corbit, 2012). 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 "find the one in the picture". The drawing was then removed from view, and 2 choice objects were presented – a target and a foil – approximately 30cm apart and equidistant from the participant. There were three trial types: standard-familiar (SF), control-familiar (CF) and standard-unfamiliar (SU). Every child completed 12 trials in total (4 of each type). In SF trials, the choice objects were familiar and belonged to distinct linguistic categories (teddy bear, spoon, cup, hairbrush, plastic banana, cow, key, cat). For each child, pictures of four objects were randomly selected. The four referents (targets) were randomly paired with one of four objects that did not appear in a picture (foils). Crucially, children's picture-object matching in SF trials could be scaffolded by verbally labelling the picture and matching to a referent object with the same label. In CF trials, the choice objects were familiar but belonged to the same linguistic categories (2 cars, 2 bottles, 2 shoes, 2 dogs). For each child, pictures of four different objects were randomly selected. The four referents (targets) were always paired with the non-depicted object belonging to the same category (foils). Although, the items in CF 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. In SU trials, the choice objects were unfamiliar objects that were perceptually distinct (lollipop mould, tassle toy, cat toy, knife sharpener, dough cutter, pom-pom, cone from a click-catch game, bottle opener). For each child, pictures of four objects were randomly selected. The four referents (targets) were randomly paired with one of four objects that did not appear in a picture (foils). The order of trial types was randomised for each participant, subject to the criterion that no more than two trials of the same type (SF, CF or SU) were presented consecutively.

In accordance with standard coding criteria (e.g. Hartley & Allen, 2015a; Allen, Hartley & Cain, 2015; 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 1 for that trial. If they incorrectly identified the foil, they scored 0. Total scores could range from 0-12 and performance on each trial type could range from 0-4.

Picture production task. Children completed the drawing task reported by Kirkham and colleagues (Kirkham et al., 2013). Children were asked to draw six unfamiliar objects, presented one-by-one. The novelty of these items ensured that children's responses could not be facilitated by pre-practiced drawing routines associated with familiar concepts. All of the objects could be drawn using lines and/or circles – the first markings that appear in children's earliest representational drawings (Levin & Bus, 2003). Thus, difficulties producing representational drawings in this task would indicate symbolic deficits, rather than motor difficulties (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?"). 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. Following Kirkham et al., (2013), participants were randomly assigned one of six 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 10 minutes to produce each drawing.

Every drawing was coded by the first experimenter and one independent rater with expertise in the field who was blind to the objectives of the experiment, the participant's details (e.g. their diagnosis, their age etc), and whether the trial was Modelled or

Unmodelled. The second experimenter presented the drawings to each rater individually, and 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). Inter-rater reliability was very high (k = .90, p < .001).

Results

Picture comprehension

In total, children with ASD scored 82.1% correct responses on average, while TD children scored 81.25%. Children with ASD scored 87.5% correct responses on standard-familiar trials, 85% on standard-unfamiliar trials, and 73.75% on control-familiar trials. By comparison, TD children score 91.25% on standard-familiar trials, 85% on standard-unfamiliar trials, and 67.5% on control-familiar trials.

A series of two one-sided Schuirmann–Welch tests (TOST) were conducted to establish whether the picture comprehension skills of language-matched TD children and children with ASD were statistically similar. The Schuirmann–Welch TOST is a popular and widely-accepted method of assessing whether two means are equivalent, that does not require population variances to be equal (Dannenberg, Dette & Munk, 1994; Gruman et al., 2007; Schuirmann, 1987; Walker & Nowacki, 2011). Opposite to conventional difference tests, the null hypothesis for TOST is that the two mean values are *not* equivalent, while the alternative hypothesis states that they are essentially equal. TOST assesses whether the difference between two distributions falls within an interval considered to represent theoretical equivalence (known as the equivalence margin). Taking into consideration our modest sample sizes and the numbers of each trial type (0-4), we regarded differences smaller than d = ± 0.8 (Cohen, 1988) as falling within the margin of equivalence (accommodating differences of ± 15.8-22.5% depending on trial type). A 90% confidence interval for the difference between the two means is calculated and compared with the margin of equivalence. The test yields two *p* values (one for each side of the confidence interval); if both are < .05, the 90% confidence interval for the mean difference falls completely within the margin of equivalence, and the two samples are judged to be equivalent. Decisions are based on the larger of the two *p* values (the smaller value is not reported).

Our TOST results are displayed in Table 1. All *p* values were < .05, suggesting that the picture comprehension of children with ASD and TD children was practically equivalent for each trial type, plus overall score. Thus, when matched to controls on language comprehension and production, linguistically-delayed children with ASD do not differ on their ability to match pictures to referent objects.

[insert Table 1 here]

As we predicted variation across trial types, data from the two populations were collapsed (due to the lack of differences), and entered into a single-factor repeated measures ANOVA (trial type: SF, CF, SU). The results revealed a significant main effect of Trial Type, $F(2, 78) = 8.32$, MSE = 0.74, $p = .001$, η^2 partial = .18. Pairwise comparisons with the Bonferroni adjustment indicated that performance on both standard-familiar trials (*M* = 89.5% correct) and standard-unfamiliar trials (*M* = 85% correct) did not differ. However, performance on both of these trial types was significantly greater than on control-familiar trials (*M* = 70.75% correct; *p* = .004-.009). Our findings show that TD children and children with ASD performed identically across trial types, exhibiting weaker performance on control-familiar trials relative to standard-familiar and standard-unfamiliar trials. Additional analyses confirmed that picture comprehension by male and female TD children did not significantly differ, and between-population effects were not affected by participant gender.[2]

[2] As our samples were not matched on gender, we conducted follow-up analyses to explore the influence of this variable. Firstly, we confirmed that male and female TD children did not significantly differ on chronological age, non-verbal abilities, language comprehension, language production, picture comprehension, or picture production. Secondly, we re-ran the ASD vs TD comparisons including only the male children, which yielded identical results to the main TOST

We then identified which background characteristics *relate* to children's concurrent picture comprehension skills. We initially conducted a series of correlations (see Table 2). For children with ASD, picture comprehension negatively correlated with autism severity (R = -.52, p = .02), and positively correlated with language comprehension (R = .65, p = .002), language production (R = .66, p = .002), and non-verbal IQ (R = .52, p = .02). For TD children, picture comprehension positively correlated with both language comprehension (R = .61, p = .005) and language production (R = .54, p = .01). However, we also observed significant relationships between variables that related to picture comprehension in both populations, indicating multicollinearity.

[insert Table 2 here]

Our next step was to elucidate which of the related variables statistically predicted variation in picture comprehension skills, while accounting for multicollinearity between background characteristics. For children with ASD, we examined the variance inflation factors (VIF) for language comprehension, language production, autism severity, and non-verbal IQ. The VIF values for language comprehension and language production were high at 4.07 and 5.5 respectively, indicating substantial multicollinearity. Given the reduced VIF values for autism severity (1.9) and non-verbal IQ (2.2), we addressed this issue by calculating the average of children's language comprehension and language production ages, yielding a single measure of 'overall language' ability (thus accounting for the extremely strong positive correlation between these two variables, R = .86, p < .001). Alongside autism severity and non-verbal IQ, overall language ability was entered into a stepwise regression that predicted picture comprehension in children with ASD. The analysis yielded a significant model, F(1, 18) = 15.58, MSE = 3.29, p = .001, containing only overall language (β = 0.68)

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analyses. Thus, we can be confident that the imbalance of female participants across samples did not significantly influence the results.

which accounted for 46% of variation in performance (see Table 3 for full details of the models).[3] All other variables were non-significant predictors (p = .27-.56) and were excluded.

For TD children, we examined the VIF values for language comprehension, language production, chronological age, and non-verbal IQ. All values ranged between 1.2-1.7, indicating minimal multicollinearity. These four variables were entered into a stepwise regression that predicted picture comprehension in TD children. The model was significant, $F(1, 18) = 10.45$, MSE = 1.96, $p = .005$, containing only language comprehension age equivalent ($\beta = 0.66$) which accounted for 37% of variation in performance. All other variables were non-significant predictors (p = .16-.96) and were excluded.

Together, these results show that picture comprehension skills in both TD children and children with ASD are statistically predicted by their current language skills.

[insert Table 3 here]

Picture production

One child with ASD scored 0 on the picture production task because their responses were uncodable scribbles, and were therefore excluded from the following analyses. As every other child produced codable responses, we are confident that both populations had sufficient fine motor skills to create representational drawings of our stimuli. In modelled trials, children with ASD scored 96.42% on average, while TD children scored 91.55%. In unmodelled trials, children with ASD scored 92.89% on average, and TD children scored 86.55%.

[3] We examined the overlap in picture comprehension variability predicted by language comprehension and production (in the ASD sample) by conducting two further stepwise regressions. Overall language ability was replaced by language comprehension in one, and language production in the other. Both models were significant (F = 13.4-13.91, p = .001-.002), with language comprehension and language production being selected as the only significant predictors (accounting for 43% and 44% of variance in their respective models). Viewed alongside the analyses above, these results suggest that language comprehension and language production do not have distinguishable influences on picture comprehension abilities in children with ASD.

TOSTs were conducted to identify whether the picture production skills of language-matched TD children and children with ASD were equivalent (see Table 1). The margin of equivalence (d = ± 0.8) accommodated differences of ±12-17%. The results revealed that total scores and scores on modelled trials were equal, but the mean difference confidence interval for unmodeled trials extended fractionally beyond the margin of equivalence (children with ASD showed an advantage over TD children). Additional analyses confirmed that picture production by male and female TD children did not significantly differ, and between-population differences were not related to participant gender (see footnote 1).

As above, we explored relationships between children's background characteristics and their concurrent picture production skills. For children with ASD, the correlational analyses showed that picture production did not significantly relate to any other variable (see Table 2). For TD children, picture production was only related to chronological age (R = .45, p = .046), which accounted for 20% of variability. As no other significant relationships were identified, a regression was not conducted for picture comprehension in TD children.

These findings suggest that picture comprehension and production are supported by different developmental abilities in both children with ASD and TD children. While picture-object mapping was supported by language skills in both populations, picture production was unrelated to language.

Discussion

The present study examined picture comprehension and picture production skills in linguistically-delayed children with ASD and TD controls matched on both language comprehension *and* language production. In one task, children identified 3-D referents of black-and-white line drawings in conditions that afforded or inhibited linguistic scaffolding. In another task, children created drawings of unfamiliar objects either spontaneously or following a demonstration. Based on evidence that language production contributes to pictorial understanding in typical development (Callaghan & Rankin, 2002; Kirkham et al., 2013), we expected to observe no differences between populations. Our findings support this hypothesis; when matched on both language measures, linguistically-delayed children with ASD are equivalent to TD controls on tasks that involve picture-object mapping or the production of basic visual representations.

The results of the picture comprehension task revealed identical patterns of performance for TD children and children with ASD. Both groups performed similarly (and highly accurately) when choice referents belonged to visually distinct categories in standard-familiar and standard-unfamiliar trials, despite the difference in labelling support. This suggests that neither population was dependent on matching verbal labels when deciphering picture-referent relations. The least accurate performance for both groups was observed in control-familiar trials that presented referents belonging to the same category that were more visually similar. Thus, it may be that perceptual discriminability of referent objects had a stronger influence on children's success than their access to linguistic scaffolding. Alternatively, it is possible that children utilised both perceptual discriminability and verbal labels when possible, but these cues varied in their usefulness across trial types. It may be that viewing pictures of familiar objects generates a verbal label (i.e. in standard-familiar and control-familiar trials) that is utilised by the picture comprehension system. While the verbal label is useful in standard-familiar trials, it may have interfered with responding in the control-familiar trials (searching for the "dog" when two dogs are present may be confusing). By contrast, this interference is not present in the trials involving unfamiliar objects – as no label is generated, children may spontaneously utilise perceptual discriminability. We recommend that future research tease apart these two explanations.

For the ASD group, statistical variability in picture comprehension abilities was predicted by 'overall language' (the average of language comprehension and language production), but not non-verbal intellectual functioning. The fact that non-verbal IQ did not predict picture comprehension (and equivalent performance was observed despite their significantly lower IQ scores) suggests that previously reported differences in pictorial understanding in ASD may not be due to deficits in intellectual functioning (Hartley & Allen, 2014a, 2014b, 2015a, 2015c). Rather, the present findings support prior evidence that language comprehension relates to picture comprehension in ASD (e.g. Hartley & Allen, 2015b) and demonstrate that language production also contributes. Greater development in the expressive verbal domain may scaffold acquisition of the pictorial system in ASD by improving children's ability to communicate (and understand communication) about pictures, attune their attention to perceptual cues that constrain picture-object relations, create and transmit symbolic meaning associated with graphic markings, and affording the ability to mentally substitute visual symbols for linguistic symbols while the picture system is fragile (Callaghan & Rankin, 2002). At a theoretical level, our findings hint that symbol systems may not develop independently in ASD. Rather, these results align with Vygotskian social-cultural theories which propose that language – the most prevalent and privileged symbol system in human culture – organises and facilitates the acquisition of non-verbal symbol systems (Callaghan & Rankin, 2002; Kirkham et al., 2013; Tomasello, 2003; Vygotsky, 1962, 1978). However, when expressive language acquisition and usage is severely impaired, there may be downstream consequences for the pictorial domain (as observed in minimally-verbal individuals; Hartley & Allen, 2014a, 2014b, 2015a, 2015b; Preissler, 2008). By comparison, receptive and expressive language appeared to make unique contributions to picture comprehension in the TD group, with only the former predicting significant variability. This suggests that competent picture-object mapping by children with typical development and ASD may be scaffolded by different aspects of language.

The picture production task revealed minimal differences between children with ASD and TD controls. The two populations performed equivalently on modelled trials, and the children with ASD showed a slight advantage on the more challenging unmodelled trials. Nevertheless, both groups created high proportions of clearly identifiable drawings in both trial types, demonstrating their competence with and without social scaffolding. The ASD sample performed particularly well, with eighty percent of children achieving ceiling scores. The resulting lack of statistical variability in the distribution likely explains why no significant correlations were identified. By contrast, variability in picture production by TD children positively correlated with concurrent chronological age, rather than language. This suggests that representational drawing and picture comprehension in young TD children may be related to, or supported by, different developmental mechanisms. Whereas interpreting others' pictures may be linked to language, the ability to create one's own pictures of unfamiliar objects may be more strongly influenced by fine motor skills or domain-general perceptual abilities that mature with age. For example, translating a sensory perception of a 3-D object into 2-D graphical markings draws on myriad visual perception and mental representation abilities (e.g. planning, organisation, segmentation) that develop over the course of early childhood, enabling the reproduction of visual-spatial details (Bouaziz & Magnan, 2007; Willats, 2005). The quality of TD children's representational drawings also increases as a result of rapid development of fine motor skills between 3 and 9 years (Cherney, Seiwere, Dickey, Flichtbeil, 2006).

Despite their highly similar performance to the TD controls, it is important to acknowledge that our ASD sample still displayed significant language impairments; their average chronological age was 11 years but their language comprehension and production age equivalents were approximately 4.5 years. However, as a group, their performance was not inhibited by substantial delays in their language development nor early delays in expressive language acquisition (a prevalent characteristic of autistic development; Anderson et al., 2007; APA, 2013). If developing expressive language facilitates children's understanding of how pictures relate to words and objects, it may be that deficits in pictorial understanding diminish once children's verbal skills reach a sufficient threshold. For individuals who remain minimally-verbal, difficulties understanding the representational nature of pictures may persist. This would have important implications for children's learning and usage of picture-based communication interventions such as PECS. It may be that children who display profound deficits in expressive language treat pictures as signs rather than symbols (Hartley & Allen, 2014a). Through repeated associative pairing, children may learn that manipulating certain pictures leads to possession of desired objects or directs others' behaviour in favourable ways, without understanding the symbolic relationship between the pictures and their referents. This is demonstrated by previous evidence that PECS-users with ASD often fail to realise that information directed at pictures (e.g. verbal labels) actually relates to their symbolised referents (Hartley & Allen, 2014b; Hartley & Allen, 2015a; Preissler, 2008).

Naturally, we must consider the limitations of this study. Our data do not directly address *causal* developmental inter-relationships between pictorial and linguistic domains. To test our theoretical speculations, it will be necessary to explore the emergence of language and picture skills via a longitudinal study. Incorporating additional assessments of pretend play (another symbol system that is atypical in ASD; Jarrold, Boucher, & Smith, 1993; Stanley & Konstantareas, 2007) and measures of social-cognition (e.g. e.g. imitation, gaze-following, intention reading, declarative pointing, joint attention) would highlight how ASD impacts symbolic development more broadly. We recognise that recruiting larger sample sizes would have increased the statistical power of the regression models. As such, the results from these analyses should be regarded with a degree of caution. It is possible that variation in representational drawing ability was influenced by differences in fine-motor ability. Thus, it would have been beneficial to take an additional measure of this ability. Finally, despite performing equivalently to TD controls in the present study, we cannot rule out the possibility that our ASD sample would show atypical pictorial understanding in different tasks. For example, they may show deficits in learning and generalising novel words from pictures (Hartley & Allen, 2014b, 2015a), or inferring artists' representational intentions

(Hartley & Allen, 2014a, 2015c). Further research is required to explore how developments in expressive language relate to these important aspects of pictorial understanding in ASD.

In summary, this study presents the first evidence that linguistically-delayed children with ASD do not show impairments on basic picture comprehension or picture production tasks when matched to TD controls on both language comprehension and language production. These findings suggest that early deficits in pictorial understanding displayed by minimally-verbal individuals may diminish as their productive language skills develop. Theoretically, our study supports the premise that development in linguistic and pictorial domains may be inter-related for children with ASD (as is the case for typical development). We recommend that future studies explore this hypothesis by employing longitudinal designs and incorporating additional domains of interest (e.g. pretend play and joint attention skills) to fully assess how ASD impacts early symbolic development.

Compliance with Ethical Standards

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from parents/caregivers prior to children's participation in this study.

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