SOCIAL LEARNING MECHANISMS OF KNOWLEDGE EXCHANGE:

active communication, information seeking and information transmission in infancy

Marina Bazhydai, B.A., M.A., Ed.M.

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Declaration

I hereby declare that the work presented in this thesis has not been submitted, in whole or in part, for the award of a higher degree at this or any other university. I further declare that this thesis is a product of my own work and the intellectual content of this thesis reflects my own thinking. All experimental studies included in this thesis were completed under the supervision of Professor Gert Westermann and Dr Eugenio Parise. In addition, study 3 was conducted in collaboration with my colleague Priya Silverstein. To reflect the collaborative effort of the empirical work and the collective theoretical, methodological and stylistic contributions, I will therefore present this work in the first-person plural voice.

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Marina Bazhydai, B.A., M.A., Ed.M.

Lancaster University, UK

Statement of Authorship

Experimental Chapter 1: Eleven-month-olds selectively refer to their social partner following epistemic violations of expectation
Conception and design of study: Marina Bazhydai, Gert Westermann, Eugenio Parise
Acquisition of data: Marina Bazhydai
Data analysis: Marina Bazhydai
Data interpretation: Marina Bazhydai, Gert Westermann, Eugenio Parise
Drafting the manuscript: Marina Bazhydai
Revising the manuscript: Marina Bazhydai, Gert Westermann, Eugenio Parise
Contribution of principal author: 85%

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Conception and design of study: Marina Bazhydai, Gert Westermann, Eugenio Parise
Acquisition of data: Marina Bazhydai
Data analysis: Marina Bazhydai
Data interpretation: Marina Bazhydai, Gert Westermann, Eugenio Parise
Drafting the manuscript: Marina Bazhydai
Revising the manuscript: Marina Bazhydai, Gert Westermann, Eugenio Parise
Contribution of principal author: 85%

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Conception and design of study: Marina Bazhydai, Priya Silverstein, Gert Westermann, Eugenio Parise
Acquisition of data: Marina Bazhydai and Priya Silverstein
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Drafting the manuscript: Marina Bazhydai and Priya Silverstein
Revising the manuscript: Marina Bazhydai, Priya Silverstein, Eugenio Parise, Gert Westermann
Shared contribution of principal authors (Marina Bazhydai and Priya Silverstein): 85%

We the undersigned agree with the above stated "proportion of work undertaken" for each of the above chapter contributing to this thesis:

Marina Bazhydai: 

Priya Silverstein: 

Gert Westermann: 

Eugenio Parise: 

Dedication

To my parents,

Alla Borisovna and Anatoli Petrovich,

for always believing in me and encouraging me to think big, deep, and broad.

"Man knows himself only to the extent that he knows the world;

he becomes aware of himself only within the world,

and aware of the world only within himself".

~ Johann Wolfgang von Goethe

Посвящается моим родителям,

Алле Борисовне и Анатолию Петровичу,

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"Человек познает сам себя только в той мере,

в какой он познает мир".

~ И. Гёте

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Epigraph

"Knowledge exists to be imparted.

Our knowledge is an accumulated thought and

experience of innumerable minds".

~ Ralph Waldo Emerson

"Knowledge is the product of the interaction

between an individual and the environment,

understanding such as something

social and cultural, not just physical".

~ Lev S. Vygotsky

Preface

We live in an information society. It is the society where information is the most important commodity and true knowledge is the ultimate goal. It is also the society that pronounced the 'death of truth' and the era of 'post-truth' (Lewandowsky, Echer, & Cook, 2017). It bombards us with an abundance of mixed messages and challenges us to sift through multiple sources of information to make coherent sense of the world. Despite the postulated "cult of ignorance" (Asimov, 1980), the pursuit of knowledge, just as the much-celebrated pursuit of happiness, remains our cherished purpose. Our pursuit of truth is embedded in the social knowledge exchange process: seeking and conveying reliable information. To aid us in achieving this lofty goal, our social and cognitive toolkit helps us successfully traverse the uncertainties of the information-rich epistemic environment: through critically assessing available facts, seeking supporting evidence, evaluating expert opinions, and exerting trust in reliable sources.

How does this process unfold in early development? This thesis was motivated by the desire to trace the beginnings of information seeking and information giving, by elucidating infants' basic behaviours as active participants of the social knowledge exchange. Before being able to fully appreciate the complexities and challenges presented by the information age they are born into, do infants also navigate their epistemic environment, face uncertainty about the reliability of information and its sources, and exhibit sensitivity to others' knowledge and ignorance cues? Expounding the ontogeny of cultural transmission of knowledge can help us better understand our own ability to cope with the overwhelming abundance of (mis)information and to proceed from experiencing epistemic uncertainty, to social knowledge acquisition, to transmitting ideas worth spreading.

Abstract

Children are active participants in the social knowledge exchange process, but little is known about how this exchange manifests in the first two years of life. This thesis explores active social learning strategies underlying both knowledge acquisition and knowledge transmission in infants aged 11-24 months. Comprising three experimental chapters, this thesis demonstrates infants' sensitivity to the informative potential of their social partners and their epistemic value, their active and selective information seeking in situations of epistemic uncertainty, and their preferential information transmission based on a combination of social and non-social factors. Experimental Chapter 1 shows that 11-month-olds communicatively respond to their social partners following epistemic violation of expectation events and do so based on the social partner's epistemic status. Experimental Chapter 2 demonstrates that 12-month-olds selectively solicit epistemic information from more knowledgeable social partners when facing a situation of referential uncertainty. Experimental Chapter 3 reports that 24-month-olds' propensity for active information transmission to less knowledgeable social partners is modulated by information complexity but not the pedagogical context of information acquisition. Overall, this thesis contributes to the literature on cognitive development of social learning strategies for acquisition and transmission of knowledge, with a special emphasis on elucidating the ontogeny of active interrogative communication skills. The overarching conclusion stemming from this work highlights that far from being passive receptacles of knowledge, infants actively partake in the bi-directional process of social knowledge exchange.

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Introduction Chapter

I. Children as active participants in social knowledge exchange

The following brief introductory section situates the current thesis in a vast and largely disconnected body of research, by providing a broad overview of the literature both on children's active learning and social learning, and arguing for an integrative 'active social learning', which manifests itself in a variety of selective social knowledge exchange strategies. This section also highlights the polar theoretical views on early active social learning behaviours, rooted either in domain-specific or domain-general cognitive mechanisms, and proposes a dialogue between these positions[1]. This overview is followed by a more detailed discussion of the literature on information seeking (section II) and information giving in early childhood (section III).

I.i. Cognitive mechanisms of active social learning

Infancy presents a unique period for quickly and efficiently accomplishing a large amount of learning about the physical and social world. Children's cognitive development relies both on their first-hand exploration and interaction with others. Two metaphors have been used to explain children's impressive rate of knowledge acquisition: a child as a 'little scientist' – an autonomous explorer guided by the

[1] In this regard, the use of the terms 'origins', 'ontogeny', 'developmental precursors', 'proto-' and similar throughout this thesis do not imply a preference for neither an innate nor a learned mechanism behind the observed behaviour, as it is beyond the scope of the current work to address this fundamental distinction.

experimentation, hypothesis testing and causal learning motivations (Gopnik, 2012; Piaget, 1952), and a child as a 'little anthropologist' (Legare & Harris, 2016; Vygotsky, 1987) – a social agent embedded in the societal structure which allows for rapid and effective learning of accumulated knowledge from others. Although the fields of active learning and social learning have been developing largely independently, recently the emphasis has been made on characterising the 'active social learning' as a unifying approach (Butler, 2020; Saylor & Ganea, 2019).

The active learning approach is rooted in an autonomous engagement with available information and seeking new information to guide one's own learning. It posits that children take a constructive approach to learning, visually and manually exploring their environment: tracking patterns, testing hypotheses, making inferences, and revising beliefs based on accumulated evidence (Gopnik & Wellman, 2012; Schulz, 2012; Xu & Kushnir, 2013). Studies of the benefits of active rather than passive learning demonstrate that having control over informational input during the learning process enhances attention and memory and leads to a faster and more robust acquisition of knowledge (for reviews, see Gureckis & Markant, 2012; Markant, Ruggeri, Gureckis, & Xu, 2016).

Children's information gathering in real life, however, most often occurs in social contexts. The social learning approach presupposes observing and interacting with others to acquire information (Boyd, Richerson, & Henrich, 2011; Csibra & Gergely, 2009; Dean, Kendal, Schapiro, Thierry, & Laland, 2012; Harris, 2012; Herrmann, Hernández-Lloreda, Hare, & Tomasello, 2007; Heyes, 1994; Tomasello, Kruger, & Ratner, 1993). Knowledge exchange through a variety of social learning strategies enables transmission of accumulated culture, from basic tool use to complex community rituals, which are passed on from one generation to another, from experts

to novices. Despite the seeming dichotomy with active learning, social learning as such does not presume that children are passive receivers of knowledge. On the contrary, both approaches construe children as active and curious, discovery-oriented agents.

The active social learning approach therefore incorporates both the asocial and social aspects as dual engines of knowledge acquisition and transmission. Here, children actively participate in the social knowledge exchange by integrating what they learned through first-hand exploration, observation, imitation, pedagogical instruction or seeking others' testimony by querying them (Saylor & Ganea, 2019; Shafto, Goodman, & Frank, 2012) – to "gather just the information they want, on just the topic that interests them, at just the time they require it" (Baldwin & Moses, 1996, p. 1934) and to propagate such knowledge to others. The broad aim of the current thesis is therefore to understand how active social learning unfolds in early cognitive and social development.

The cognitive mechanisms underlying active social learning are a topic of unresolved debate. Broadly, some proposals emphasize the top-down, conceptual and innate predispositions specialised by genetic evolution, such as language or 'rich' indices of mentalising and intentionality in infants' behaviour (Csibra & Gergely, 2009, 2011; Spelke, Bernier, & Skerry, 2013; Tomasello, 1999; Tomasello, Carpenter, Call, Behne, & Moll, 2005). For instance, the 'core knowledge' theory posits that infants' basic social cognition evolved as an innate, domain-specific adaptation, along with other systems such as spatial or numerical cognition (Spelke et al., 2013). Strong evidence in support of this account comes from studies of infants in their first weeks of life (that is, prior to the ability to observe a statistically substantial number of physical events), nevertheless responding in surprise (indexed by longer looking) when viewing events which are physically impossible according to adult judgements, such as objects

crossing through a solid wall or violating the principle of gravity (Spelke & Kinzler, 2007). The core knowledge domains are said to encompass, aside from object knowledge, motion and spatial knowledge, numerosity, geometrical forms, social agency and emotions. Supporting evidence from non-human species suggests that some of these may be indeed innate at least in part (Vallortigara, 2012). However, preventing fully innate claims, since infants tested in these paradigms had already had at least some experience in the world, they could have acquired the necessary rudimentary experience rather than were born with these abilities.

Other proposals, on the other hand, highlight the bottom-up, mechanistic, 'lean' processes specialised through associative learning or via cultural inheritance (Galef, 2013; Kendal, Boogert, Rendell, Laland, Webster, & Jones, 2018; Heyes, 1994, 2017; Leadbeater, 2015; Sobel & Kushnir, 2013; Whiten, 2000). At the core of these kinds of approaches is the premise that cognitive mechanisms evolve and are inherited through social learning (Heyes, 2020), underscoring the importance of dynamic interactions between developmental mechanisms and experience (Spencer, Blumberg, McMurray, Robinson, Samuelson, & Tomblin, 2009). For example, the predictive processing framework would explain infants' responses to unexpected events, as described above, in terms of expectations that were formed through the learning experience history (Köster, Kayhan, Langeloh, & Hoehl, 2020). Similarly, the utility-based theories argue that infants acquire the ability to act rationally and optimally through statistical learning processes, incorporating the ability to computed the weighted combination of multiple epistemic (or knowledge-related) and social goals (Bridgers, Jara-Ettinger, & Gweon, 2020; Shafto et al., 2012).

In other words, infants might either be already cognitively equipped for effective social learning due to specific evolutionary adaptations, or their cognitive system is

quickly adapting through early learning experiences due to powerful domain-general mechanisms. Despite the variety of theoretical stances regarding its underlying mechanisms, active social learning approach proposes that rather than being passive recipients of knowledge from others, infants actively participate in the social knowledge exchange process. Using many strategies, children not only quickly acquire knowledge from social partners, but also themselves transmit it to others. How do they accomplish this?

I.ii. Social knowledge exchange strategies

Socially mediated transmission of knowledge is a powerful mechanism for adaptive learning. Such learning is less evolutionary costly than the relatively unconstrained, independent trial-and-error exploration as it allows learners to bypass the need for the first-hand exploration every step of the way, and instead presents knowledge already verified and in the 'pre-packaged' format through the accumulated experiences of others (Boyd, Richerson, & Henrich, 2011; Kline, 2015; Whiten, 2000). At the core of cultural transmission is the learner's capacity to flexibly and effectively engage in a variety of social learning strategies, such as observation, imitation, emulation, active information solicitation, and pedagogy (Kendal et al., 2018).

Direct observation of others is guided by the learner's attentional mechanisms and allows them to acquire new information about their environment, which they could have possibly discovered on their own at a later time, yet social learning facilitates more efficient sharing of knowledge among conspecifics (Call & Carpenter, 2002; Galef & Whiten, 2017; Hoppitt & Laland, 2013; Paradise & Rogoff, 2009). The primary social learning strategies are imitation – faithfully copying others' actions – and emulation – applying what has been learned to different contexts by replicating the outcomes of actions rather than the exact behaviours observed. As excellent imitators, children can

copy with high fidelity a sequence of actions demonstrated by another person to achieve a goal (Nielsen, 2006; Over & Carpenter, 2012; Want & Harris, 2002). Imitation and its counterpart, the so-called overimitation or the overly faithful imitation (where the learner copies all of the actions of the social partner, regardless of their causal links with the actual action outcome), extend beyond goal-directed actions to the exclusively cultural domain (for a review, see Hoehl, Keupp, Schleihauf, McGuigan, Buttelmann, & Whiten, 2019). Emulation, on the other hand, emphasises the instrumental action outcome without much regard to the process of how the goal was achieved (McGuigan & Whiten, 2009; Tennie, Call, & Tomasello, 2006; Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009). Although observation, imitation and emulation are the strategies humans share with many other animals, other forms of active social learning may be uniquely human.

While all social learning strategies concern transmission of knowledge from one social partner to another, this thesis focused specifically on infants' active social learning strategies of information seeking and information giving. Intentionally posing requests for information to social partners allows children to direct their own acquisition of knowledge (Baldwin & Moses, 1996). Children are sensitive to others' ability to provide useful information and take an interrogative stance towards them as sources of knowledge (Harris, Koenig, Corriveau, & Jaswal, 2018; Poulin-Dubois & Brosseau-Liard, 2016). Even preverbal infants use information seeking gestures to solicit information from social partners, with their communicative strategies becoming more varied and complex with the mastery of language (for reviews see Lucca, 2020; Ronfard, Zambrana, Hermansen, & Kelemen, 2018; section II of Introduction Chapter, Experimental Chapters 1 and 2).

Children can also obtain knowledge from others who are willing and able to share what they know – via direct pedagogical instruction or intentional teaching. As compared to other social learning strategies, pedagogy facilitates acquisition of more complex knowledge and skills (Morgan et al., 2015; Zwirner & Thornton, 2015). A theory of Instructed Learning (Tomasello, 2016) argues that this social learning process evolved to not only enable knowledge transfer, but also establish common ground and social coherence. A theory of Natural Pedagogy (NP, Csibra & Gergely, 2009, 2011) proposes that humans are uniquely predisposed to learn from social partners who display ostensive communicative cues, which signal transmission of generic and generalizable knowledge. Infants' early sensitivity to these cues indicates their readiness to learn and treat this information differently (we return to these key theories in more detail in section III.i of the Introduction Chapter). Other cognitive development theories similarly emphasise social facilitation of the learner's input through apprenticeship, direct demonstration and feedback as teaching models, e.g., Zone of Proximal Development (Vygotsky, 1987) and Guided Participation (Rogoff, Mistry, Göncü, Mosier, Chavajay, & Heath, 1993). Asking children questions has been shown to be an effective pedagogical strategy (Yu, Landrum, Bonawitz, & Shafto, 2018), also helping to mitigate the detrimental effects of direct pedagogy on further exploration and learning (Bonawitz, Shafto, Gweon, Goodman, Spelke, & Schulz, 2011).

Children's own active teaching allows them to convey knowledge they acquired to less knowledgeable others (Butler, 2020; Kline, 2015; Strauss, Ziv, & Stein, 2002). Despite the paucity of empirical research on the ontogeny of teaching, studies have shown that infants start to engage in basic preverbal information transmission (Liszkowski, Carpenter, Striano, & Tomasello, 2006) and preschoolers spontaneously teach their younger siblings, who, in turn, spontaneously request teaching (Howe, Della

Porta, Recchia, & Ross, 2016). With social and cognitive development and an expanded teaching strategies toolkit, children gradually become more contingent and selective in their teaching (for reviews, see Corriveau, Ronfard, & Cui, 2018; Ronfard & Harris, 2018; section III of Introduction Chapter, Experimental Chapter 3).

I.iii. Selectivity in active social learning

Children's initiation of information seeking from others based on their ability to provide information and children's propensity to transmit obtained information to others based on the mode of knowledge acquisition and evaluation of the information source is at the core of the studies comprising this thesis. As children engage in seeking information and transmitting acquired evidence socially, their choices are often selective. This selectivity primarily manifests through sensitivity to others' cues of reliability, accuracy, confidence and credibility, as well as informants' age, ingroup status, endorsement by others, and deference to majority, among others (Harris, 2012; Mills, 2013; Sobel & Kushnir, 2013). Understanding the ontogeny of selective social learning sheds light on the later developing, more complex accounts of selective trust in others' testimony (Clément, 2010; Harris et al., 2018) and knowledge clustering (Danovitch & Keil, 2004).

Evidence amounts that infants are sensitive to reliability and accuracy of information and of people who supply it (Harris & Lane, 2014; Poulin-Dubois & Brosseau-Liard, 2016). A study with 8-month-olds showed that infants differently treated reliable information provided through social cues, such as human faces, as compared to other symbolic but non-social cues, such as arrows (Tummeltshammer, Wu, Sobel, & Kirhkam, 2014). While infants were able to track the reliability of both types of cues and used this information to make predictions when facing uncertainty, they were only willing to generalise social but not non-social reliability cues in novel

contexts. Reliability and accuracy cues play an important role in infants' interaction with social partners in their second year of life: they selectively choose to follow their gaze (Chow, Poulin-Dubois, & Lewis, 2008), reference them in emotionally ambiguous situations (Stenberg, 2013), look longer at them upon detecting their inaccurate testimony (Koenig & Echols, 2003), imitate their actions (Poulin-Dubois, Brooker, & Polonia, 2011; Zmyj, Buttelmann, Carpenter, & Daum, 2010), and request labels for novel objects from them (Begus & Southgate, 2012; Kovács, Tauzin, Téglás, Gergely, & Csibra, 2014). In a word learning context, toddlers are more likely to retain novel words learned from previously reliable speakers (Brooker & Poulin-Dubois, 2013; Koenig & Woodward, 2010), generalise words to novel contexts (Luchkina, Sobel, & Morgan, 2018), and reject novel labels for familiar objects from previously inaccurate or ignorant informants (Krogh-Jespersen & Echols, 2012).

In addition to epistemic indices, infants exhibit selectivity to social cues, such as preferentially learning from adults versus peers (Kachel, Moore, & Tomasello, 2018; Zmyj, Daum, Prinz, Nielsen, & Aschersleben, 2012) and from ingroup rather than outgroup members (Buttelmann, Zmyj, Daum, & Carpenter, 2013). Demonstrating the increasing importance of social credibility cues, 24-month-olds but not 18-month-olds preferentially learned from people who presented themselves as confident rather than actually knowledgeable (Birch, Akmal, & Frampton, 2010; Brosseau-Liard & Poulin-Dubois, 2014). Despite the early emerging sensitivity to informants' trustworthiness, older children sometimes gullibly accept inaccurate or unreliable information, prioritising group membership and social affiliation, such as consensus between multiple informants or familiarity over objectively credible testimony (Corriveau & Harris, 2009; Jaswal & Konrad, 2016), as well as making inferences about social partners' ability to provide information based on their perceived personality traits

(Lane, Wellman, & Gelman, 2013). Nevertheless, a recent set of meta-analyses reported that preschoolers exhibit selective trust based on both epistemic and social characteristics of informants, with older children attributing higher weight to the knowledge dimension rather than social status (Tong, Wang, & Danovitch, 2020).

Children's sensitivity to an interplay between social and epistemic motivations in knowledge acquisition contexts can be illustrated by a set of studies contrasting learning from native and non-native speakers. Measuring brain's theta oscillations as a neural signature of information anticipation, an electrophysiological study showed that 11-month-old infants expected to learn new information from people who were previously informative as opposed to those who did not provide any information, as well as from native speakers as opposed to foreign speakers (Begus, Gliga, & Southgate, 2016). However, the follow-up work showed that infants were just as likely to anticipate learning from the foreign speaking individuals if they were previously informative as from the native speakers (Begus & Gergely, 2017). Thus, infants' information expectation was higher when they could plausibly expect to learn something, resolving the conflict between social and epistemic goals in favour of the latter. A longitudinal study with preschoolers came to similar conclusions: the quality of information becomes more important for children than the informant's social status (Corriveau, Kinzler, & Harris, 2013). Furthermore, with advances in cognitive development, preschoolers flexibly update their epistemic representations of informants in light of new evidence of their credibility and are able to retrospectively revise acquired knowledge if needed (Clegg, Kurkul, Corriveau, 2019; Gillis, Nilsen, & Gevaux, 2019; Hoicka, Butcher, Malla, & Harris, 2017; Leech, Haber, Arunachalam, Kurkul, & Corriveau, 2019; Luchkina, Corriveau, & Sobel, 2020; Nurmsoo & Robinson, 2009; Ronfard & Lane, 2018, 2019).

The debate regarding the nature of underlying cognitive mechanisms broadly in the field of active social learning similarly applies to the reviewed selective learning literature (Clément, 2010; Heyes, 2017; Poulin-Dubois, 2017; Sabbagh, Koenig & Kuhlmeier, 2017). A variety of mechanisms has been proposed in both the domain-general and domain-specific camps, broadly grouped. The associative learning account rests on the idea that simple statistical associations are responsible for the selective choice of informants through implicit calculations, categorisations and generalisations made from previous encounters with these individuals. A more complex process, the Bayesian learning inference, highlights that cognitive computations and inferential predictions are accessible not only to the human brain, but even to the 'ideal learner' computational model (Landrum, Eaves, & Shafto, 2015; Shafto, Eaves, Navarro, & Perfors, 2012). These domain-general accounts stand in contrast to the domain-specific mechanisms, which are rooted in the theory of mind (ToM) – the ability to attribute mental states to oneself and others, such as understanding that agents with minds have intentions, beliefs, desires, knowledge, etc. According to these accounts, even young infants possess abilities which can be deemed as proto-mentalistic and proto-metacognitive reasoning, that is, while lacking the ability to explicitly reason about mental states, infants may nevertheless exhibit early, rudimentary ToM-like skills (Gergely et al., 1995; Király, Oláh, Csibra, & Kovács, 2018; Mascaro & Sperber, 2009; Setoh, Scott, & Baillargeon, 2016; Sperber et al, 2010).

One proposal that reconciles both kinds of approaches, the 'dual-process account' (Heyes, 2016), posits that early on, it is the implicit associative learning that likely fully explains the observed selectivity in social learning, while with the development of ToM, the domain-specific, unique to humans, explicit, and experience-dependent mechanisms take over. In a similar vein, the 'rational evidence selection'

proposal incorporates children's abilities to track associative evidence, as well as make causal inferences and social judgements (Sobel & Kushnir, 2013). Research with older children shows that ToM and selective trust abilities are positively related (Di Yanni, Nini, Rheel & Livelli, 2012; Fusaro & Harris, 2008), and so are ToM and the ability to select relevant and useful information when teaching others (Bass, Bonawitz, Shafto, Ramarajan, Gopnik, & Wellman, 2017). However, direct evidence investigating this relationship in infants who are not yet able to pass the standard ToM tasks so far is inconsistent (Crivello, Phillips, & Poulin-Dubois, 2018; Kuzyk, Grossman, & Poulin-Dubois, 2020), highlighting the need for further research into the ontogeny and development of selective trust in others' testimony.

In sum, emerging evidence suggests that even preverbal infants are able to quickly process the social distribution of knowledge by taking an active epistemic stance. If they can identify trustworthy informants who are available and willing to supply evidence, can they also take an interrogative stance towards them by employing active and selective communication? Section II of the current chapter reviews the state of the literature on infants' active communication and information seeking in the process of knowledge acquisition from others, highlighting epistemic curiosity processes in epistemic uncertainty contexts and focusing on the preverbal behaviour of social referencing as an interrogative signal. Section III of the current chapter provides a review of infants' active information transmission behaviours in view of the main theoretical approaches, early behavioural manifestations and selectivity in teaching choices.

II. Active communication and information seeking

The following section reviews the literature on curiosity in social learning, with a focus on epistemic (or knowledge-related) curiosity, which manifests itself in the most pronounced way in various situations of epistemic uncertainty through the early developing active information seeking behaviours. Specifically, the presentation of the proposal and the accompanying evidence that pointing may serve an interrogative function is followed by the review of the emerging literature suggesting that social referencing may be another information seeking behaviour.

II.i. Curiosity in social learning

Infants are often described as naturally curious learners, keen on acquiring knowledge through independent exploration, as well as through their social partners. Curiosity can be viewed as an inherent interplay between autonomous and social processes, and as such, a catalyst of social learning and epistemic development broadly speaking. Curiosity is generally defined as active information seeking motivated by internal rather than external rewards. A useful classification was proposed by Berlyne (1960) who distinguished between perceptual and epistemic and between specific and diversive dimensions of curiosity. This two-dimensional taxonomy captures a range of behaviours, including those that pertain to infants, from the targeted search for a particular bit of information to the broad sampling of the environmental affordances, and from the tactile stimulation seeking to the pursuit of knowledge.

Developmental roots of curiosity lie in early infancy. From the first months of life, infants engage in visual exploration, later mastering sustained visual examining of objects (Oakes & Tellinghuisen, 1994; Yu & Smith, 2016). With development of motor skills, exploration extends to the haptic domain, enabling multi-modal examining of objects' properties and affordances (Gibson, 1988; Lockman, 2000; Rochat, 1989).

With onset of locomotion, infants' exploratory activity leads to enhanced information acquisition in an expanded array of learning domains, such as spatial and language abilities (Bertenthal, Campos, & Kermoian, 1994; Iverson, 2010). In social contexts, infants pay special attention to people's faces, people who look at them or speak to them using child-directed speech (Cooper & Aslin, 1990; Farroni, Csibra, Simion, & Johnson, 2002; Morton & Johnson, 1991). As infants themselves start to participate in communicative acts, producing non-verbal signals such as vocalizations and emotional facial expressions, they learn to use social interactions for information seeking. Among such preverbal communicative acts are babbling (Goldstein, Schwade, Briesch, & Syal, 2010), holding out and giving objects of their interest to other people (Boundy, Cameron-Faulkner, & Theakston, 2016), using social referencing to seek social input (Striano, Vaish, & Benigno, 2006), and pointing to learn about objects of their interest (Begus & Southgate, 2012). Just as visual scanning and motor exploration are tools to gain information about the environment independently, early communicative behaviours are tools to obtain information from others (for reviews see Begus & Southgate, 2018; Butler, Ronfard, & Corriveau, 2020; Lucca, 2020; Ronfard et al., 2018, and section II.iii. of the current chapter).

A set of core theories have proposed several, though not mutually exclusive, cognitive mechanisms that underlie curiosity (for reviews see Bazhydai, Twomey, & Westermann, 2019; Kidd & Hayden, 2015; Loewenstein, 1994; Silvia, 2012). Earliest psychological theories viewed curiosity as a drive, similar to other natural biological drives such as hunger or thirst (Hall & Smith, 1903) – an aversive state that motivates reflex-like drive reduction behaviours aimed at restoring the lost balance. The later wave of drive theories conceptualised curiosity as a new kind of drive, an exploration drive (Fowler, 1965; Hebb, 1958) – an intrinsic, reward-based motivation to obtain

information, rather than the basic need to resolve an unpleasant experience. While foundational for the scientific study of curiosity, the classic drive models failed to accommodate the complexity and flexibility of human curiosity, as well as incorporate fully its social dimension. Conceptualisations of curiosity that appeared subsequently attempted to do that.

Incongruency approaches to curiosity are rooted in people's distinct responses to information that is novel, surprising and complex (Berlyne, 1960, 1966; Hebb, 1949). Detecting such information necessitates the motivation to reduce the incongruency between existing internal representations and incoming conflicting information, and to update such representations through cognitive assimilation or accommodation processes (Piaget, 1969). Infants' behaviours reflecting such motivation range from basic orienting reflexes (Fantz, 1964; Sokolov, 1963) and preferential attentional deployment (Baillargeon and Graber, 1987; Wynn, 1992), to increased visual and manual exploration (Sim & Xu, 2017; Stahl & Feigenson, 2015) and to seeking others' input upon observing novel, surprising and complex phenomena. Among examples of this latter, social dimension, are infants' social referencing towards their caregivers upon encountering an unexpected emotional or cognitive challenge, such as facing a perceived visual drop-off or a novel self-propelling toy (e.g., Feinman, 1982; Sorce, Emde, Campos, & Klinnert, 1985) or receiving false or incongruent information (e.g., Dunn & Bremner, 2017; Koenig & Echols, 2003; Mireault, Crockenberg, Sparrow, Pettinato, Woodard, & Malzac, 2014), pointing to novel toys (e.g., Begus & Southgate, 2012; Kovács et al., 2014), or asking clarifying and explanation-seeking questions (Frazier, Gelman, & Wellman, 2009; Tizard & Hughes, 1984). Incongruency theories are applicable to both perceptual and epistemic curiosity, adopting the two-dimensional classification of curiosity (Berlyne, 1960). The other two major theories of curiosity,

information gap and learning progress, pertain to the epistemic dimension, which is the focus of the current thesis.

While the incongruency approach to epistemic curiosity is "akin to scratching a mental itch", the information gap approach is like "filling a mental hole" (Silvia, 2012; p. 158). According to this theory (Loewenstein, 1994), curiosity arises in order to close the epistemic gap between the current and desired knowledge states. Frequently used with adult participants, this approach presumes that an individual is aware of the existing information gap and strategically acts to obtain missing knowledge to fill it, acting with awareness of the amount of information that is needed (Gottlieb, 2018; Gruber, Gelman, & Ranganath, 2014; Kang, Hsu, Krajbich, Loewenstein, McClure, Wang, & Camerer, 2009). Older children also initiate information seeking to fill their identified information gaps by interrogating people who can provide such information (Jirout & Klahr, 2012; Lucca, 2020; Ronfard et al., 2018). However, the information gap theory as such may be inadequate to explain curiosity in preverbal infants who lack metacognitive skills to detect such a gap and act upon such realisation (Gottlieb & Oudeyer, 2018; Kidd & Hayden, 2015).

On the contrary, learning progress theories are well suited for studying cognitive mechanisms of curiosity in infancy (Gottlieb & Oudeyer, 2018; Oudeyer, Gottlieb, & Lopes, 2016; Oudeyer & Smith, 2016). This approach is guided in part by the early Piagetian account of children as active learners, "little scientists", who strategically interact with the environment through active exploration and play to facilitate their information gain. Infants' curiosity here arises to maximise learning progress, that is, to most efficiently obtain knowledge and reduce prediction errors. The underlying processes are proposed to be intrinsic and occur outside of the learner's awareness. Such optimal learning takes place through independent exploration and through seeking

information from social partners to achieve the learning progress goals. Studies in the developmental robotics field showed that a robot-initiated exploration involved its designated 'caregiver' to achieve learning goals when it was most optimal (Forestier & Oudeyer, 2017). Interactions with human caregivers provide infants with tools to enhance exploratory activities and reinforce curiosity, such as scaffolding sustained observation skills to extend the opportunities for knowledge acquisition (Suarez-Rivera, Smith, & Yu, 2019; Yu & Smith, 2016). Social partners themselves can be sources of knowledge that infants can tap into (Begus & Southgate, 2018; Harris, Koenig, Corriveau, & Jaswal, 2018). Thus, the learning progress approaches account for infants' curiosity in both independent and social learning exploration.

In sum, epistemic curiosity often takes place in social contexts and manifests in infants' active social learning through interaction with suitable (familiar, friendly, or knowledgeable) social partners who can help fulfil infants' information seeking goals and maximize their epistemic benefit. Viewed through these lenses, the very core of social knowledge exchange is fuelled by epistemic curiosity. Especially conducive to investigating the ontogeny of infants' active communication motivated by epistemic goals are situations of epistemic uncertainty.

II.ii. Epistemic uncertainty in social contexts

A decision to seek information is more likely to arise in a situation necessitating the need for such information, that is, in a situation of epistemic (or informational, rather that affective or perceptual) uncertainty – when one's previously formed expectations are violated, when no information is available to solve the problem, or when conflicting, unreliable, insufficient, clearly inaccurate, or ambiguous information is provided. Studies detected infants' implicit, neural responses to situations when adults demonstrated unexpected ambiguous actions, such as bringing a spoon to one's ear

rather than a mouth (Köster, Langeloh, & Hoehl, 2019; Reid, Hoehl, Grigutsch, Groendahl, Parise, & Striano, 2009), or deliberately mislabelled familiar objects (Parise & Csibra, 2012). Less is known about infants explicit behavioural and communicative responses to epistemic uncertainty situations.

Infants show sensitivity to the levels of informational uncertainty before the development of explicit metacognitive skills (Carruthers, 2020; Goupil & Kouider, 2016; Kim, Sodian, & Proust, 2020). Studies of epistemic uncertainty in infants and preschool age children demonstrate an increase in autonomous and social information seeking following such events. Infants approach and explore the unexpected (Stahl & Feigenson, 2015; Sim & Xu, 2017), turn to others to obtain situational information (Goupil, Romand-Monnier, & Kouider, 2016; Stenberg, 2012; Vaish, Demir, & Baldwin, 2011), and point to learn about novel toy labels (Begus & Southgate, 2012; Lucca & Wilbourn, 2018, 2019).

Preschoolers explore ambiguous novel toys and try to independently reason about the underlying causal mechanisms (Legare, Gelman, & Wellman, 2010; Schulz & Bonawitz, 2007), as well as pose questions to others when they themselves are unable to find an answer (Choinard, 2007; Harris, Bartz, & Rowe, 2017). Older children strategically seek information from social partners who they deem the best sources of relevant expertise, critically assessing when to trust and when to exert doubt on others' testimony in order to acquire sufficient information to problem-solve (Mills, Legare, Grant, & Landrum, 2011; Mills, 2013). Despite preschoolers' overwhelming inclination to endorse the testimony of trustworthy others even when it is counter-intuitive to their own perceptual judgement (Li & Yow, 2018; Ronfard, Chen, & Harris, 2018; Ronfard, Lane, Wang, & Harris, 2017), they nevertheless seek to resolve uncertainty by clarifying their understanding of the fact or idea (Frazier et al., 2009; Tizard & Hughes,

1984), obtain satisfactory, non-circular responses to causal questions (Kurkul & Corriveau, 2018), or obtain new evidence when lacking confidence in their own knowledge (Coughlin, Hembacher, Lyons, & Ghetti, 2014).

Infants' demonstrated ability to act, both independently and socially, in an epistemic environment suggests the developmental lag between their explicit knowledge understanding and their actual, observable behaviours, in that while lacking the ability to reflect on the need for information or reasoning behind seeking particular information, preverbal infants nevertheless exhibit such behaviours. One of the broad aims of the current thesis is therefore to investigate in more nuance infants' information seeking from others when facing epistemic uncertainty in order to elucidate the ontogeny of question-asking (Butler, Ronfard, & Corriveau, 2020). What are the communicative skills that enable infants' interaction with social partners to satisfy their epistemic goals?

II.iii. Development of information seeking

Social information gathering is at the core of cultural transmission of knowledge (Baldwin & Moses, 1996; Csibra & Gergely, 2006; Spelke et al., 2013; Tomasello, 1999). How do infants accomplish information solicitation prior to emergence of language? Preverbal infants' communicative repertoire includes social gaze, reaching, pointing, and vocalizing. These behaviours are among the early communicative tools available for seeking emotional guidance when uncertain, asking for help, and placing instrumental requests (Bates, Camaioni, & Volterra, 1975; Tomasello, Carpenter, & Liszkowski, 2007; Walden & Ogan, 1988). Recent accounts further proposed that through the early emerging interpersonal sensitivity, these behaviours may also enable curiosity-driven, active social learning, aimed at gathering information about the immediate environment from someone who can be regarded as familiar with it, thus

serving an interrogative, or information seeking function (Baldwin, 2000; Beier & Spelke, 2012; Grosse, Behne, Carpenter, & Tomasello, 2010; Harris & Lane, 2014; Southgate, Van Maanen, & Csibra, 2007). As such, these preverbal behaviours may be the earliest precursors to fully developed, mature social information seeking through posing verbal questions.

Interrogative pointing

Among communicative tools most pronounced in their function to seek information is index-finger pointing – a behaviour that emerges between 11 and 18 months. Such prelinguistic pointing has been closely linked with language development and therefore regarded as one of the most important milestones in early cognitive development (Bates, 1979; Colonnesi, Stams, Koster, & Noom, 2010). Traditionally, infants' pointing has been classified into the earlier emerging imperative and later developing declarative (Bates, Camaioni, & Volterra, 1975). Imperative pointing – a request to obtain an object – assumes an immediate reward goal, whereas declarative pointing aims at indicating an object of interest and constitutes a more advanced form of behaviour produced as a tool for communication rather than an egocentric expression. More recently, two additional motives for infants' pointing have been proposed – informative (Tomasello, Carpenter & Liszkowski, 2007) and interrogative (Southgate et al., 2007).

The proposed informative pointing can be exemplified by a study reported by Liszkowski, Carpenter and Tomasello (2008), which showed that infants used pointing selectively to provide ignorant social partners with needed information. Overall, extensive work on pointing production and comprehension converges that in the second year of life, infants use pointing appropriately and selectively, with some understanding of social intentions. For example, when parents share their interest in an object, infants

point declaratively, when they request an object, infants offer it to them, and when parents point informatively, infants search for the information alluded to (Esteve-Gibert, Prieto, & Liszkowski, 2017). Thus, infants understand when social partners provide them with information both through verbal and non-verbal means of communication and start to produce similar communicative signals themselves.

Theorists have also argued that infants recognize an interrogative motive in their non-verbal communication, such that the emergence of index-finger pointing marks the transition from infants' selective attention to information to explicitly requesting information, rather than an actual object as in imperative pointing, from their social partners (Franco & Butterworth, 1996; Lucca, 2020; Harris, 2020; Southgate et al., 2007). In a seminal study in support of this hypothesis, Begus and Southgate (2012) showed that at 16 months, infants pointed to the novel objects presented in front of them only when the experimenter seated across from the infant has proven to be previously informative. If the experimenter had a history of mislabelling or appeared unsure in labels she provided, infants were less likely to point towards a novel object that was shown to them, as if hesitating to seek labelling information from the poorly informed social partner. Kovács et al (2014) built on this paradigm and showed that already at 12 months, infants seek new information from knowledgeable adults. In the initial study, infants who interacted with an informative experimenter were more likely to point in their presence than infants who interacted with an experimenter providing engagement but no information. In the follow-up study, infants used interrogative pointing more when their interlocutors provided novel labels to ambiguous toys (e.g., "dax" when presented with an atypical member of the car category – a racing car) than when they provided familiar labels to the same ambiguous toys (e.g., "car"). These studies suggest that pointing infants are able to use this communicative tool to selectively request

information from others, not just share their experience with others (declarative) or ask for the object (imperative).

Interrogative pointing has been also shown to uniquely facilitate knowledge gain. Begus, Gliga, and Southgate (2014) showed that after 16-month-olds pointed towards an object of their interest, they were significantly more likely to learn that object's function when it was presented immediately after infants pointed toward that object, than when this information was provided for an object not pointed to. Lucca and Wilbourn (2018) further demonstrated that pointing is uniquely positioned to offer such learning advantage as compared to other communicative cues, such as reaching or looking, and expect specific information in response to their points (Lucca & Wilbourn, 2019). Infants therefore not only take an interrogative stance, but also direct their own learning through pointing gestures.

Pointing emerged as a pronounced pre-linguistic means to seek information from others. But does this mean that interrogative communication begins only with emergence of pointing and is not available to pre-pointing infants? Even before mastering pointing themselves, infants understand its communicative function (Krehm, Onishi, & Vouloumanos, 2014). It has been proposed that pointing foundationally relies on the ability to establish joint attention (Baldwin, 1991) and best facilitates learning when coupled with this earlier emerging cognitive achievement (Tomasello & Farrar, 1986). Supporting evidence comes from a longitudinal training study (Matthews, Behne, Lieven, & Tomasello, 2012) in which caregivers were asked to deliberately teach their 9-11-month-olds to point towards objects on a daily basis. However, training itself was not a significant predictor of pointing a month later; rather, infants' gaze following ability was. Earlier development therefore might hold cues to cognitive mechanisms that underlie it. What are the developmental precursors to interrogative

pointing? We argue that social referencing is one of such plausible precursors and review in the following sections both the classic accounts of social referencing and the recent studies that share the proposed interrogative perspective.

Social referencing as information seeking

It has been long noted that infants pay special attention to human faces, which may underlie their predisposition to learn about the world through a caregiver's face (Farroni, Csibra, Simion, & Johnson, 2002; Frank, Amso & Johnson, 2014). With development, looking at others allows them to obtain crucial feedback on the situation. For instance, infants check in with their caregivers upon encountering a potentially dangerous situation, such as an obstacle on their path, a barking dog, or a spider. Social referencing is comprised of two behavioural elements: initiating a look at the adult and using adult's emotional cues in guiding further actions (Walden, 1991). Thus, if the caregiver is not showing any signs of distress when the infant references them, the infant would cease being worried as well. A number of studies utilizing this approach informed the definition for a behaviour classically termed social referencing, underlying the importance of affective processes in the ontogeny of social learning (Campos & Stenberg, 1981; Clément & Dukes, 2017; Feinman, 1982; Walle, Reschke, & Knothe, 2017).

Several theories have been proposed to explain the development of social referencing behaviour. Early emergence theories (Campos & Stenberg, 1981; Vaillant-Molina & Bahrick, 2012; Walden & Ogan, 1988) propose that social looking arises in response to novel or ambiguous events as early as 6 months. In contrast, Baldwin and Moses (1996) and Schaffer (1984, 1989) argue that intentional information seeking social referencing behaviour does not occur until after 12 months, only after a year of social learning and development of the ability to infer communicative intentions in

social interactions. These latter accounts propose that successful active social knowledge gathering is dependent on infants' implicit understanding of communicative acts and meanings transmitted through them, as well as assessing their own need for information and using communicative cues to achieve their information-driven goals, which is not possible until the second year of life. To adjudicate between these competing accounts and between low-level, associative, and higher-level, cognitively rich explanations, a developmental perspective can be adopted (Bruner, 1999; Feinman, Roberts, Hsieh, Sawyer & Swanson, 1992; Southgate, 2019). According to such approach, social referencing in the first year of life may constitute information seeking with rudimentary understanding of intentional communication, which is nevertheless sufficient to solicit timely and reliable transfer of knowledge from social partners. Whether or not preverbal infants have a full grasp of intentionality of their communicative acts, they do learn a great amount of new and useful information through initiating a social gaze, which may be a genesis of social information exchange. With development, social referencing as information seeking becomes more cognitively sophisticated.

Social referencing as affective information seeking

A number of classic studies best exemplify what is typically referred to as social referencing. Sorce et al (1985) watched as 14-month-olds approached a visual cliff and manipulated mothers' facial expressions as positive or negative. Infants were keen on checking in with their mothers before making the decision whether to cross the cliff or not, but only when the cliff was deep and not shallow. This receptivity to emotional expressions of other, trusted people has been viewed as a primary function of social looks. Zarbatany and Lamb (1985) investigated social referencing as a function of the information source – mothers rather than strangers. A toy spider served as an

uncertainty provoking stimulus for 14-month-olds. Depending on the facial expression of joy or fear on the mothers' or the strangers' face, infants selectively utilized this emotional information only from mothers. Further, infants used unfamiliar adults' emotional reactions only when their expressions were relevant to the object, but not when adults' access to relevant information was in question, e.g., an adult whose view of the toy was occluded by a barrier (Moses, Baldwin, Rosicky, & Tidball, 2001). It stems from these studies that infants are able to appreciate, deliberately seek, and incorporate intentional emotional expressions from their trusted adults into their decision making about the encountered emotionally uncertain situation.

Social referencing propensity is also affected by stimulus ambiguity and situational uncertainty. For instance, upon receiving affective information in the paradigm similar to the visual cliff situation described above, 18-month-olds used it selectively only when their own perceptual uncertainty was high (Tamis-LeMonda, Adolph, Lobo, Karasik, Ishak, & Dimitropoulou, 2008). Infants faced a slope of different angles and were first given an opportunity to independently assess whether it was safe, risky, or borderline. If their own assessment of the risk was high but the emotional reaction received from the caregiver was positive, infants were less likely to accept her encouragement to cross. Similarly, when the caregiver projected discouragement for safe slopes, infants ignored her advice. Crucially, in the borderline uncertainty cases, infants deferred to caregivers' advice. Building on this study, Kim and Kwak (2011) tested younger infants at 12 and 16 months by presenting them with a variety of toys chosen to elicit infants' positive, negative, or ambiguous reactions. Ambiguous (but not positive or negative) toys elicited higher rates of social referencing and prompted infants to incorporate emotional responses to their social looks into their decision whether to approach or avoid the toys. Infants are therefore able to both assess

first-hand evidence and selectively seek other's guidance in situations of uncertainty.

An important point of discussion has been whether social referencing in uncertain situations constitutes information seeking or attachment motivated behaviour (Ainsworth, 1992; Stenberg & Hagekull, 2007; Striano et al., 2006). First, it has been demonstrated that social referencing is not selectively used with caregivers, but also with other, familiar and unfamiliar, adults (Stenberg & Hagekull, 2007; Striano & Rochat, 2000; Stenberg, 2009). In contrast with the exclusive attachment-based proposal, Striano and Rochat (2000) found that 10-month-olds referred to the experimenter when she was attending to the ambiguous stimulus (remote-controlled barking dog toy). Similarly, Stenberg and Hagekull (2007) found that infants preferred to look at the experimenter rather than their caregiver when presented with ambiguous toys and acted in accordance with relevant information received from referencing them, which was explained from the perspective of the situational expertise account, since experimenters in the laboratory environment are more likely than infants' caregivers to be knowledgeable about the ambiguous toys they presented, where they, rather than the caregiver, are 'in charge'. This, however, could be explained by the lower-level, associative learning process, since it was the experimenter who handled the toys, rather than the caregiver. Furthermore, social referencing may have been driven by a novelty or surprise effect – a simple association with a new person and a new environment.

Controlling for these lower-level explanations, the following set of findings provided stronger support for the expertise rather than attachment (or comfort seeking) account of social referencing. This work builds on the proposal that infants are sensitive to the social distribution of knowledge and make use of this in their selective social referencing behaviour (Feinman et al., 1992; Stenberg, 2009, 2013). Stenberg (2003, 2009, 2012, 2013) demonstrated that infants solicit input from situational experts rather

than familiar people, indicative of their ability to appraise the epistemic dimension of environmental uncertainty. In one study, regardless of whether the caregiver or the experimenter presented the ambiguous toy, infants referred more to the experimenter (Stenberg, 2009). Here, thus, when a situational expert was an unfamiliar experimenter, infants were more likely to refer to them rather than their primary caregiver, who in this context was as uncertain about the situation as the infant herself. Experimenters' familiarity and expertise was manipulated systematically in another set of studies, demonstrating that more familiar and more competent adults attracted more social referencing looks when they provided positive information about ambiguous toys (Stenberg, 2012), and expert adults attracted more social referencing, regardless of their familiarity (Stenberg, 2013).

In sum, classic accounts of social referencing propose that children refer to social partners to gather their reactions to uncertainty which is affective in nature, in order to determine how to appropriately react to it. However, with development, the same behaviour can become less emotionally laden, transforming into strategic information seeking rather than social appraisal seeking. More recent studies open a possibility that social referencing serves a cognitively rich function of epistemic information seeking as proto-interrogative, requestive acts, which are developing before interrogative pointing (for reviews, see Begus & Southgate, 2018; Harris & Lane, 2014). The following section reviews the emerging research of infants' social referencing in the context of non-affective information transmission.

Social referencing as epistemic information seeking

Following research on pointing as an interrogative request and social referencing as emotional appraisal seeking, recent studies started to explore social referencing as a behaviour signalling a request for epistemic information. These

experimental reports focused on situations of cognitive-perceptual ambiguity rather than unpleasantness or perceived danger – situations of epistemic uncertainty described as being "slightly out of the ordinary", i.e., with a lower threshold of uncertainty than the typical highly emotionally arousing paradigms (Nishida & Lillard, 2007). New reports show that infants refer to their social partners when their expectations are violated (Dunn & Bremner, 2017; Koenig & Echols, 2003; Walden, Kim, McCoy, & Karrass, 2007), upon detecting humorous situations (Mireault et al., 2014), and to obtain episodic or generic information (Harris et al., 2017; Goupil et al., 2016; Lucca & Wilbourn, 2018; Vaish et al., 2011). These studies challenge the long-standing view that social referencing seeks others' socio-emotional engagement and is not fully intentionally communicative until the second year of infant's life (Baldwin & Moses, 1996; Schaffer, 1984, 1989; Walden & Ogan, 1988). We review some of these studies in more detail below.

A set of studies of social looking in a word learning context reported how infants respond to a semantic violation of expectation (VoE) – blatant object mislabelling by an adult (e.g., calling a shoe a duck rather than a shoe; Koenig & Echols, 2003). These studies showed that 16-month-old infants regarded knowledgeable social partners (as opposed to adults who did not have access to information, adults who did not provide a label or non-social, inanimate source of information) as useful informants in situations of uncertainty. When a human speaker labelled an object incongruently rather than congruently, infants looked significantly longer to them. However, when the human speaker was positioned to face away from objects she was labelling, infants looked longer to her instead in congruent trials, as if surprised that a person with no perceptual experience of an object would be able to label it correctly. These findings are consistent with the results of Dunn and Bremner (2017), showing that 6-month-old infants

responded with social looks to events violating core physical properties of objects (e.g., when an initially presented object was covertly switched for a different object), but less so to events that were merely novel. These results stand in contrast to the well-established looking time measure, which here was not sensitive enough to differentiate the two events. It remains unclear if 6-month-olds' social referencing can be explained by the higher level of uncertainty in the VoE event as compared to the lower level of uncertainty novel event, thus instead eliciting socio-emotional checking in with the caregiver rather than actually seeking information. Nevertheless, collectively such studies highlight that just like affective uncertainty, epistemic uncertainty reliably elicits infants' social referencing.

Does social referencing in presence of epistemic uncertainty indicate selective information seeking? Vaish, Demir and Baldwin (2011) presented 13- to 18-month-old infants with either one or two novel objects, designed to induce referential ambiguity when only one label was provided by the experimenter. Indeed, infants looked at the experimenter more in the uncertainty situation when two objects were presented. In the first experiment, only the first trial of the two produced the significant result, which the authors associated with fatigue effects, and subsequently, the second experiment was limited to one trial. Further, the significant primary outcomes differed across the two studies: duration of looks in first experiment and the number of looks in the second experiment (for a broader discussion of this matter, refer to the section V.iii. Choice of outcome measures). Despite these methodological considerations, the study showed that when presented with two novel objects and only one novel label, infants as young as 13 months responded to this referential ambiguity with more social looking at the speaker. Furthermore, to eliminate the alternative explanation that infants may have simply oriented to the speaker uttering the label rather than sought information from

them, the experimental design featured a baseline phase when no novel labels were provided. There were no significant differences in social referencing in the presence of one versus two novel objects in a baseline phase, suggesting that infants indeed actively sought clarification before mapping a novel word onto a novel object. Overall, this research suggests that social looking may not be selectively used in emotional uncertainty, and is not only an indicator of attention to the social context or the speaker, but could also be a communicative tool used for epistemic (in this case, referential) information seeking. However, while infants' looks here can be interpreted as if asking "Which one?", the design of this study does not fully rule out the possibility that infants may have oriented to the speaker to establish joint attention on the situation deemed unusual or ambiguous, without the explicit information seeking intention.

Building on the Vaish et al. (2011) paradigm, Hembacher and colleagues (Hembacher, de Mayo, & Frank, 2017; Hembacher, de Mayo, & Frank, 2020) investigated selective social referencing in word learning in 2-5-year-old children. In their task, children were asked to make an active choice of the object following the experimenter's labelling which differed in the level of presented uncertainty, from the mutually exclusive situation when one novel object and one familiar object were presented, to the fully ambiguous situation when both objects were novel. Social referencing was coded at four experimental phases, from the time the label was provided to the time the child made an object choice. Children made social looks when they anticipated information gain, that is, only when objects presented referential ambiguity and they were not able to make the correct choice independently (using the principle of mutual exclusivity). Interestingly, infants did not gaze selectively at the experimenter when she was providing the labels, which is in contrast with the Vaish and colleagues' (2011) study. This may be due to the differences in design flow (e.g., the direction of

the labeller's gaze, the number of practice and test trials, the presence or absence of comprehension trials, whether infants were able to hold objects and at what stage in the procedure, and the level of uncertainty that was manipulated) or in the age group sampled (13-18 vs 2-5 year olds). But it also leaves open the possibility that infants may use social referencing as a communicative signal both when referential ambiguity is being presented to them (during the labelling; Vaish et al., 2011) and when they need to make an explicit behavioural decision themselves (during the object choice following the experimenter's labelling; Hembacher et al., 2017). Overall, this study showed that social referencing increases, becomes faster and more proactive with development (from 2 to 5), as children continue to use social gaze interrogatively even after additional communicative tools (pointing and verbal) are developmentally available to them.

Another group of studies suggests that infants use social gaze as a way to ask for missing information upon recognising their own ignorance. In one report, children aged 16-33 months were shown a mix of pictures, where some represented familiar items (e.g., book, bird), and other unfamiliar items that children could not name. Children's looks at the speaker and their expressions of doubt and ignorance (e.g., "Umm…"; "I don't know"; asking adult: "What's that?) were positively associated (Harris et al., 2017). Similarly, in another study, 20-month-old infants had to remember which box contained the toy and choose the box they thought it was in after a delay of varied length (Goupil, Romand-Monnier, & Kouider, 2016). Infants in the experimental group were trained to ask their caregivers for help by looking at them, while the control group infants had to respond to the memory test without such help. Infants in the experimental condition used social referencing more, especially when their uncertainty at test was high, such as in impossible trials (when the object was hidden outside of infants' awareness) or trials with longer delays before the memory retrieval phase. It

was interpreted as infants acting strategically to avoid making errors by declining difficult choices – not responding when they did not know where the toy was, but instead initiating a social look at their caregiver who was able to provide an answer. The plausibility of an alternative explanation exists, however, that social referencing was motivated by the adults' contingent responsiveness in the experimental but not in control condition. Furthermore, despite being trained to do so, a large proportion of infants in the experimental condition never asked for help, and while the control group was not trained to ask for help, they still occasionally did so spontaneously, which may be indicative of a socio-emotional rather than strategically interrogative motivation for social referencing. Despite the limitations, these results suggest that preverbal infants seek help from knowledgeable others to obtain information they are lacking due to epistemic uncertainty.

Notwithstanding the progress made in the literature reviewed in this section, a question whether social referencing looks, construed as explicit communicative behaviours, underlie epistemic information seeking during epistemic uncertainty remains controversial, warranting further systematic investigation. Experimental Chapters 1 and 2 directly contribute to addressing this issue.

III. Active information transmission

The previous section reviewed the current state of the literature on children's early propensity to seek information from their social partners. In line with the bi-directional nature of the social knowledge exchange process, the current section focuses on children's ability to transmit the knowledge they acquired from social partners to others. We present existing evidence that infants' remarkable ability to direct their own knowledge acquisition by actively seeking input from social sources is mirrored by their ability to convey the acquired evidence to conspecifics.

To investigate children's active social learning, this thesis asked how children who learn from different social partners, some who are more knowledgeable and others less so, or some who are actively teaching them while others are not, start to transmit acquired knowledge to others who are more ignorant. To focus on characterizing the manifestations of information transmission observable in early development, in this thesis, despite the debated differences (e.g., Kline, 2015; Skerry, Lambert, Powell, & McAuliffe, 2013; Strauss & Ziv, 2012), we use the term 'teaching' as a synonym to 'information giving', 'information sharing', 'information propagation', and 'information transmission', in line with the broad definition of teaching as a "behaviour that evolved to facilitate learning in others" (Kline, 2015, p. 2).

III.i. Cognitive mechanisms of information transmission

Teaching is an essential element of human cumulative culture (Kline, 2015; Thornton & Raihani, 2008). Not only are children efficient recipients of others' teaching – their own teaching behaviours may be key to understanding the very nature of information transmission which enables cultural evolution (Ronfard & Harris, 2015; Strauss, Calero, & Sigman, 2014). However, the basic underlying cognitive and social mechanisms of teaching in children are poorly understood (Corriveau, Ronfard, & Cui,

2018; Paulus, Kim, & Sodian, 2015; Pasquinelli & Strauss, 2018). This section briefly describes four broad theoretical approaches addressing this problem, which we called behavioural, natural cognitive ability, mentalistic, and pedagogical (for relevant reviews and alternative taxonomies of theoretical approaches see Kline, 2015; Skerry et al., 2013; Pasquinelli & Strauss, 2018).

Animal and comparative research proposed that teaching, in its minimalist behavioural form, is an evolutionary adaptation also present in nonhuman animals (Caro & Hauser, 1992; Thornton & Raihani, 2008). Here, teaching is characterised by a modified behaviour of a teacher, who uses specific reinforcement strategies to provide an experience or an example to a naïve learner, as a result of which the learner masters a skill or obtains knowledge which would be otherwise unobtainable or obtainable only later in life. Importantly, teaching presents no immediate benefit and is costly to the teacher though beneficial to the learner. In observed animal behaviour, teaching is hard-wired, specific to the problem (e.g., locating food sources or prey-handling) and contingent (requires active engagement of both the teacher and the learner). For example, in ants, if the learner and the teacher inadvertently lose contact during the teaching session, the learner begins to independently explore the surroundings to try to solve the food search problem on its own, and once the teacher is able to re-establish contact with the learner, immediately returns to the 'teaching session' (Franks & Richardson, 2006). Teaching in humans, as opposed to animals, is characterised by its flexibility, diversity, and domain-generality (Burdett, Dean, & Ronfard, 2017; Hoppitt, Brown, Kendal, Rendell, Thornton, Webster, & Laland, 2008). In accordance with this evolutionary behavioural approach, high skill and high value information is more likely to be explicitly taught rather than learned through other social learning strategies, such as observation or imitation.

The natural cognitive ability approach is specific to humans and proposes that teaching undergoes a developmental change, from proto-teaching in infants who have not yet developed a theory of mind, to emergent teaching when such capacities appear in ontogeny (Strauss et al., 2002; Strauss & Ziv, 2012; Strauss et al., 2014). At the core of this approach lie the arguments that teaching is a human universal and a spontaneously emerging behaviour that becomes more complex and sophisticated with development yet occurs without the need for explicit awareness of the underlying logic of one's teaching choices. An extension of this reasoning, a constructionist approach has been proposed to characterise the building blocks which might be common to both simple and more complex forms of teaching and thus to build a bridge between the variety of approaches and account for rudimentary teaching behaviours in animals (Pasquinelli & Strauss, 2018).

According to the mentalistic approach, teaching relies on understanding of own and others' mental states, accomplished upon a teacher recognising a knowledge gap between themselves as knowledgeable and others as ignorant, and intending to close this knowledge gap (Premack, 2007). Consequently, this approach applies when children start to appreciate teaching as a special communicative act that leads to a change in beliefs (Gelman, Ware, Manczak, & Graham, 2013; Rhodes, Bonawitz, Shafto, Chen, & Caglar, 2015; Sobel & Letourneau, 2016). The key aspect of this approach is demonstrated by studies that explored the relationship between children's understanding of their own teaching behaviour and their theory of mind skills (Sobel & Letourneau, 2016; Ziv & Frye, 2004). However, the findings that even adults are not always aware of the underlying logic of their teaching (Strauss, 1993), the debates about the early emergence of intentionality (Gergely, Nádasdy, Csibra, & Bíró, 1995) and the proposed existence of the 'implicit theory of mind' in infants (e.g., Scott & Baillargeon,

2017) cast doubt on the fundamental reliance of teaching on mentalising capacity. Mitigating these discrepancies, it has been further proposed that rather than teaching as such, it is specifically the selective and high-quality contingent teaching that is dependent on children's mentalising, metacognition, as well as executive function skills (Corriveau et al., 2018). According to this approach, advanced, selective teaching is a function of children's understanding of knowledge distribution in social interactions (Ronfard et al., 2017; Ziv, & Frye, 2004; Ziv, Solomon, Strauss, & Frye, 2016).

The pedagogical approach as described here broadly encompasses several prominent theories, united despite the important differences between them by converging evidence of early infants' sensitivity to other's pedagogical communication. According to the theory of Instructed Learning (Kruger & Tomasello, 1996; Tomasello, 2016; Tomasello & Carpenter, 2007), the teacher provides information both for epistemic and social reasons. Pedagogical behaviour here is construed as inherently prosocial, such that the transfer of information occurs to facilitate cooperation and social coordination. Efficacy of teaching is largely reliant on children's propensity for faithful imitation following enhanced sensitivity to pedagogical demonstrations. As a socially salient mechanism of knowledge transfer, teaching allows members of the social group to not only achieve epistemic unity, but also to achieve common ground. This reasoning explains to a large extent the human propensity to transmit normative and conforming information to their ingroup members. While not conceptualised as such explicitly, it can be inferred that according to this approach, infants are not only receptive to this kind of pedagogy but themselves engage in transmitting information to others driven by prosocial motivation, and do so as early as 12 months via informative pointing behaviour (e.g., Liszkowski et al., 2006; Tomasello et al., 2007; see section III.ii Development of information transmission, for more details of these studies).

Another prominent theory which fits broadly under the umbrella of the pedagogical approach to teaching conceptualisation, Natural Pedagogy (NP; Csibra & Gergely, 2009, 2011), places utmost importance on children's receptivity to cognitively opaque and generalisable information explicitly communicated with the use of ostensive cues. This special type of communication signals that the knowledge being conveyed is relevant and generic, and that the communicator is knowledgeable and helpful. While the NP theory does not directly address children's own teaching abilities, it has been proposed that pedagogy as a teaching strategy should be applicable both to adults and children themselves, and as such enables fast and efficient bi-directional transfer of culturally relevant knowledge (Ronfard & Harris, 2018; Strauss et al., 2014). In support, research documented children's own spontaneous use of ostensive cues when teaching others, which included direct eye gaze, informing gestures, contingent and verbally explicit signals (Calero, Zylberberg, Ais, Semelman, & Sigman, 2015; Calero, Goldin, & Sigman, 2018; Whiten & Flynn, 2010).

Overall, NP posits that infants interpret ostensive communication from adults as teaching them generalisable, rather than episodic, information. In this thesis, we are interested at what point can infants themselves take the role of the teachers of such information. Despite the fact that NP has not explicitly contributed to theorising about child-led information transmission, the theory itself warrants deeper consideration in light of the current thesis (see Experimental Chapter 3). What NP proposes is that ostensive signalling uniquely prepares infants for learning, above and beyond increasing salience and attracting their attention. This claim has been most strongly supported by studies that showed that infants follow an adult's gaze when it is preceded by direct ostensive cues (e.g., direct gaze and infant-directed speech; Senju & Csibra, 2008; Yoon, Johnson & Csibra, 2008). However, studies have also shown that other

salient but non-ostensive cues may lead to the same effects (e.g., shievering; Gredebäck, et al., 2018; Szufnarowska et al., 2014) and some of the original findings could not be replicated (Silverstein, Gliga, Westermann, & Parise, 2019), suggesting that attentional mechanisms may be responsible for the increased learning effects. In light of these discrepancies, the inherently innate nature of NP has been subject to criticism, with alternative proposals arguing for the non-specific, domain-general adaptations view of social learning strategies, focusing on cultural and associative learning, rather than innate cognitive processes (Heyes, 2016; Nakao & Andrews, 2014).

In sum, the varied theoretical understanding of teaching has been instrumental to embracing the complexity and diversity of behaviours related to information transmission and supporting novel empirical investigations into its ontogeny. At the same time, the disciplinary differences have led to some discrepancies in results and difficulties in interpretations, which are discussed in the following section.

III.ii. Development of information transmission

Despite the wealth of theoretical advancements in understanding child-led teaching, relatively few studies have investigated the emergence of information transmission in infancy. This might be attributed both to theoretical and methodological reasons. For instance, if presuming that the cognitive prerequisites for teaching include a developed theory of mind and understanding of one's own and others' epistemic states (that the teacher intends to change the epistemic state of the learner), research questions based on such presumption might only be applicable to preschool age children, e.g., do children choose to teach those who expressed the need for information, those who are capable of learning new information, and whether they tailor their teaching to the needs of the learner. On the other hand, some evidence suggests that children's information giving emerges spontaneously as early as 12 months, which can be explained by the

behavioural, teaching as natural cognitive ability, and pedagogical, but not by the mentalising approach, as outlined in the preceding section. Here, the appropriate research questions could focus on the prevalence of certain information transmission behaviours across development and social situations.

To account for such inconsistencies and unite several theoretical approaches, Strauss and Ziv (2012) proposed a developmental taxonomy of teaching strategies, which we adopt in the current thesis. This taxonomy advances from *proto-teaching* – transmission of the here-and-now, episodic information, such as pointing to a location of a hidden object – to *emergent teaching* of generic and generalisable information, such as a label or a function of an object, to adult-like *systematic contingent teaching*. In this transition, children master a range of teaching strategies, such as direct assistance, demonstration, explanation, and specific response to learners (e.g., checking in, scaffolding, providing feedback, offering praise). For example, the basic demonstration as a teaching strategy entails a teacher highlighting pertinent features of information (e.g., the rules of the game), with or without the learner's direct or contingent involvement or the teachers' consideration to the learner's mental state. A more advanced form of this teaching strategy would involve a demonstration accompanied by verbal explanations, such as describing steps required to achieve a particular action outcome. Thus, the precision of the adopted operational definition of teaching and its developmentally appropriate strategies allows for more accurate representations of children's behaviours and thoughtful interpretations of results (see also Wood, Wood, Ainsworth, & O'Malley, 1995, for an ontogenetic model of children as teachers).

Furthermore, the methodological choices are also important to consider in order to derive a coherent understanding of the existing findings. A variety of methods has been developed to elucidate the phenomenon of child-led information transmission

from different perspectives: observation studies (Howe & Recchia, 2005; Maynard, 2002), diffusion transmission chain studies (Flynn & Whiten, 2008, 2010; see detailed explanation below), tasks when children are observed as they spontaneously choose to teach another child (Ashley & Tomasello, 1998), tasks where the recipient of teaching is a puppet operated by the experimenter (Clegg & Legare, 2016; Corriveau et al., 2018; Ronfard, Was, & Harris, 2016), tasks where children are asked what they would teach if they were to (hypothetically) interact with an ignorant person (Bridgers et al., 2020), and tasks where adult experimenters play the role of an ignorant adult to prompt children's teaching in a live interaction (Calero et al., 2015; Vredenburgh, Kushnir, & Casasola, 2015), as well as computational modelling (Bridgers et al., 2020). Based on these, for example, whereas older children's 'teaching' of a puppet learner may be admissible evidence of their information giving, using such method with preverbal infants may lead to unsubstantiated conclusions, because infants may still lack a developed ability to engage in pretend play and ToM skills needed to construe puppets as agents in knowledge transmission context. Similarly, explicitly asking a preschool child about their knowledge transmission preferences may not be as effective a method as asking school-aged children, due to their developing language skills and social demands that imagining and elaborating on a hypothetical scenario presents.

In light of the described theoretical and methodological considerations, several ground-breaking studies investigated the development of child-led information transmission before preschool years. Infants have been reported to engage in informing of others as early as 12 months (Liszkowski et al., 2006; Liszkowski, Carpenter, & Tomasello, 2008). In this set of studies, infants pointed to an object to inform an experimenter who was looking for it while expressing uncertainty about its location, and did so only when the experimenter actually did not have prior knowledge about the

object's location rather than when they expressed puzzlement despite actually knowing the location. Similarly, another study of infants' informative pointing in their first year showed that they are sensitive to others' lack of specific information (Meng & Hashiya, 2014). Here, infants selectively informed the experimenter of a novel object which was introduced when the experimenter was not present in the room, despite having paid equal attention to both a familiar and a novel object. These cases of informative pointing were interpreted as infants' developing sensitivity to others' knowledge states and spontaneous information transmission to remedy the knowledge gap between themselves and the ignorant adult, rather than infants pointing for self-benefitting instrumental or declarative reasons. According to the classification proposed by Strauss and Ziv (2012), such transfer of episodic rather than generic and generalisable information would constitute proto-teaching.

Studies with toddlers demonstrate their engagement in both episodic and generic information transmission. In interaction with their caregivers, two-year-olds were more likely to point to, as well as verbally identify the new toy and its location when the caregivers did not witness its appearance, as compared to when the caregivers were present in the room when the new toy was presented (O'Neill, 1996). Thus, like infants, toddlers spontaneously share information they came to exclusively possess. Ashley and Tomasello (1998) studied peer-to-peer transmission in the context of a social cooperation task. In dyads, toddlers and preschoolers learned to perform two (relatively complex) actions to receive a reward and were then given an opportunity to teach this sequence of actions to a naïve peer. Unlike older children, two-year-olds did not succeed at neither independently learning the task nor later teaching it, which was interpreted as the lack of emerging teaching ability at this age. However, it is important to note that the potential confounding factor here was the complexity of the action sequences which

may have exceeded toddlers' cognitive and motor capacities, and the socially demanding peer context which may have exceeded toddlers' social-emotional skills.

In contrast, Vredenburgh, Kushnir and Casasola (2015) presented two-year-olds with relatively simple actions and tested their prompted transmission to a naïve adult rather than a peer. Two novel actions were demonstrated by two experimenters, one of which was explicitly pedagogical (using child-directed speech, direct eye-gaze, and verbal teaching signals), while the other intentionally demonstrated the action without such pedagogical cues. At transmission, toddlers selectively performed the action that was demonstrated to them in a pedagogical manner. This result suggests that children at this age are capable of transmitting generalisable information to another person who lacks such knowledge. In another study, Flynn (2008) also demonstrated that 2.5-year-olds were capable of transmitting learned action to conspecifics. This study used the diffusion chain method, evaluating the transmission of initially 'seeded' (or intentionally taught by demonstrators) actions and any modifications made through the chains of transmission, from knowledgeable children to naïve ones, and further down the chain as children acquired information. Interestingly, here toddlers omitted the actions that were not causally relevant when demonstrated to them, thus showing no evidence of overimitation in transmission and suggesting that children at this age transmit information in a rather pragmatic manner. This result was in line with other studies of diffusion chain transmission (as well as experimental reports, e.g., Clegg & Legare, 2016) showing that faithful imitation of actions increases with age (Flynn & Whiten, 2012).

In sum, studies with infants indicate their inclination to transmit episodic information, while studies with toddlers suggest that they might engage both in proto-teaching of episodic information, such as object location, and in emerging teaching of

generalisable knowledge, such as functional tool use. Although child-led transmission of information may have its roots in infancy, the majority of studies focused on preschool and school age children, leaving a significant gap in our understanding of the developmental trajectory of information transmission. The rapidly emerging body of research with older children, however, shows their sensitivity to what and whom they are teaching. The following section highlights the most salient features of the literature that investigated child-led information transmission as a function of the properties of information selected for transmission and as a function of the social context.

III.iii. Selective information transmission

What are the salient properties of information that is more likely to propagate? Among such non-social features may be perceptual salience, novelty, causality, efficiency, complexity, and generalisability. At the same time, salient features of the social context also affect which information children will transmit, such as pedagogical or normative context, perceived learners' expertise, goals and interests, and their social identity. A number of studies have investigated children's selective transmission based on some of these features.

Evidence from observational diffusion chain studies with preschoolers found that they are eager to teach their peers goal-directed tool actions, including those that are causally irrelevant, following their own indiscriminate copying, and often over-imitation, of actions as they learned them from an adult model (Flynn & Whiten, 2010; Whiten & Flynn, 2010). Such faithfulness in both copying and propagation of acquired information might be related to children's transmission of information that is perceived as normative or conventional. Starting in preschool age, children are keen to demonstrate how the game works and explain its rules, including intervening to teach actions that violated the rules of the game and enforce the norms specifically for the

non-compliant learners (Rakoczy & Schmidt, 2013; Strauss et al., 2002). Perceived normativity emerges from children's understanding of the social context. For instance, children corrected a learner's rule violations only when they explicitly set an example of interacting with the toy in an intentionally norm-inducing way, rather than in an exploratory manner (Schmidt, Rakoczy, & Tomasello, 2011), and when the learner explicitly expressed an intention to play a game (Rakoczy, Warneken, & Tomasello, 2008). This sensitivity to information normativity was so powerful that preschool children were more likely to teach other people actions that were inefficient if they were presented in conventional manner (e.g., "This is how we do it") (Clegg & Legare, 2016).

Complex and cognitively opaque information is another prominent candidate for transmission among preschool and older children (Ronfard & Harris, 2018). Preschoolers spontaneously selected beneficial but complex information such as mathematical concepts to teach their younger siblings (Howe et al., 2016). Children eagerly conveyed information when it was the only evidence they received and preferred to transmit information obtained using a more cognitively opaque method and one that they could not easily discover on their own (Ronfard et al., 2016). In teaching the functions of the complex novel toy, preschoolers strategically conveyed relevant and representative information and avoided redundant demonstrations that went beyond the core of the taught concepts (Rhodes et al., 2015). Similarly, children considered the utility of information that could be either explored independently or explicitly taught and adjudicated between the discoverability of toys and their reward value, choosing to teach information that was in line with the utility calculus reasoning, by minimising the expected learner's and the teacher's costs and maximising the learner's rewards, in line with the novel computational model (Bridgers et al., 2020).

Selectivity in information transmission is also based on the children's perceived characteristics of the learner and their assessment of the presence of the knowledge gap between children as knowers and an ignorant but eager learner (Ronfard & Harris, 2018). With preliminary awareness of the roles of the teacher and the learner, preschoolers (Ziv & Frye, 2004) adjust their selection of which rules of the game to teach based on the learner's specific mistakes, thus tailoring information to fill the particular gap in the learner's knowledge (Ronfard & Corriveau, 2016). A more sophisticated understanding of teaching as a process that causes knowledge change (Sobel & Letourneau, 2016; Wood et al., 1995; Ziv & Frye, 2004) enables older children's contingent teaching as they tailor their demonstrations to the learner's postulated goals (e.g., to learn about the toy rather than just observe) and their perceived competence and intelligence levels (Gweon & Schulz, 2019), select representative information with multiple examples to convey new knowledge (Rhodes, Gelman, & Brickman, 2010), and make a transmission choice based on the inferred relevance of supplied information for the receiver rather than personal interests (Danovitch, 2020). Somewhat counter-intuitively, children have also been shown to selectively provide information for those who have previously been more informative themselves over ignorant recipients (Kim, Kalish, Weisman, Johnson, & Shutts, 2016), which might, however, be indicative of prosocial, rather than purely epistemic motives driving transmission.

In sum, studies with children of preschool age and older suggest that they are able to evaluate the nature of information before its transmission, e.g., whether information is obscure or complex, generic or specific, normative or descriptive. They also evaluate the social context in which information transmission occurs, such as the learners' characteristics and their ability to benefit from teaching. Whether such

selective information transmission is available to younger children is subject to further empirical investigation.

IV. Research questions

The following section outlines the research questions that motivated this thesis and have been addressed in the three experimental chapters. What are the behavioural manifestations of infants' active participation in social knowledge exchange? This thesis asked how social and epistemic context affects this bi-directional process and what communicative signals may be developmentally and functionally appropriate to enable it.

While social learning theories focus on infants' reliance on the top-down knowledge acquisition processes, active learning theories highlight the importance of infants' bottom-up, independent information seeking as a means for learning. This thesis argues that infants equally and simultaneously engage both in active learning and in social learning. In the reported experimental work, infants were placed in various situations of epistemic uncertainty in an interactive social context, during which they could, using active social learning strategies, either obtain new information from more knowledgeable social partners (Experimental Chapters 1 and 2) or themselves propagate information to less knowledgeable social partners (Experimental Chapter 3).

Little is known about how active social learning strategies in early development could help infants resolve epistemic uncertainty. This thesis therefore asked what developmentally available communicative and information seeking signals preverbal infants use, and whether they use these cues selectively in order to obtain information. As reviewed in the Introduction Chapter, in addition to the historically more common interpretation that social referencing plays a social engagement and affective information seeking function, recent research provided support for the idea that it may also serve an interrogative function in non-emotional situations, thus framing social referencing as a way to seek information from knowledgeable adults that is not affective

in nature. The overarching question asked in the Experimental Chapters 1 and 2 is whether infants' use of social referencing is actively communicative and interrogative in two different situations of epistemic uncertainty.

Experimental Chapter 1 investigated preverbal infants' use of social referencing towards their caregivers upon detecting an object-referent mismatch as the caregivers mislabelled familiar objects, addressing research question 1: *Do preverbal infants actively respond to epistemic violations of expectation with social referencing behaviour?*

Experimental Chapter 2 investigated preverbal infants' selective use of social referencing towards unfamiliar social partners as a means of seeking unavailable information from the best source, addressing research question 2: *Do preverbal infants use social referencing to seek information from more knowledgeable adults in situations of referential uncertainty?*

Experimental Chapter 3 marks a turn from investigating active knowledge acquisition to focusing on infants' active knowledge transmission, specifically how social and epistemic context affects their propensity to propagate information to less knowledgeable social partners, addressing research question 3: *Do toddlers preferentially transmit information that was taught to them in an explicitly pedagogical context or information that was easier to demonstrate but not taught pedagogically?*

Contributing to the ongoing body of research on active learning and active teaching, this thesis therefore specifically explores the development of the information seeking function of social referencing as one of the earliest communicative signals and the earliest signs of active information transmission in infants under two years of age. This experimental work provides novel insights into social and cognitive mechanisms of cultural knowledge transmission.

V. Methodological overview

This thesis contains three experimental studies consisting of a total of six experiments which employed behavioural and eye-tracking methods. The following section provides a methodological overview of the rationale for the methodological choices.

V.i. Interactive nature of the design

The experimental approach adopted in this thesis utilised laboratory-based, live presentation interactive experimental designs. In all three studies, infants and their primary caregivers were invited to the established laboratory for infancy and early childhood studies. In study 1, infants and their primary caregivers watched a series of screen-based stimuli, with caregivers actively participating in the procedure and enabling three experimental conditions. In study 2, infants and their primary caregivers were introduced to two unfamiliar experimenters, each of whom played a role to enable an experimental manipulation, while the caregivers facilitated the procedural flow. In study 3, toddlers were interacting with three experimenters, two of whom were unfamiliar, while the caregiver was passively observing the procedure. This required rigorous use of randomisation and counterbalancing techniques, as well as extensive training to ensure standardisation of caregivers and experimenters' behaviours. Despite the inherent challenges, engaging infants in such highly interactive, dynamic, rich social environments was instrumental to the studies' research goals.

Infants' caregivers played an important role during all three experimental studies. In study 1, they were instrumental to enabling the key experimental manipulation. In study 2, they provided essential procedural support by presenting novel toys and removing them upon the trial completion, as well as posing key experimental questions to their children. Such active role of caregivers also allowed to

ensure infants did not develop a preference for one of the experimenters. In all three studies, caregivers offered assurance and support to their children, neutralising stress from entering an unfamiliar environment, minimising fussiness and alleviating shyness to engage and maintain their attention and interest.

Infants also interacted with real objects in studies 2 and 3, while study 1 used screen-based visual stimuli. It is uncontested that digital stimuli presentation affords rigorous experimental control, such as normalizing the length, attractiveness, size, and other multi-sensory information, thus allowing to elucidate the socio-cognitive processes by minimising lower-level perceptual, potentially confounding, elements. However, interaction with real multi-sensory objects contributes to strengthening the experiment's ecological validity and is beneficial for maintaining infants' attention while minimising fussiness. In studies 2 and 3, we considered the choice of familiar and novel objects and their intrinsic properties such as attractiveness, colour, shape, and complexity, although no pilot study was performed to systematically compare these properties.

V.ii. Experimental design considerations

Careful consideration was given to the procedural flow, the length of the whole procedure, the total number of trials during which infants' attention can be plausibly sustained, and the number of different sources of information (novel objects and people). We aimed at minimizing participant burden and attrition due to fussiness and inattention and keeping the task demands realistic for the age groups selected. This resulted in procedures ranging, on average, from 3.5 minutes (in study 1 experiment 1) to 15 minutes (in study 3 experiment 1 and 2).

We considered utility of the between- versus within-subject experimental designs and single versus multiple experimenter designs. Due to the explicitly social

nature of the manipulations, successful designs needed to provide the conditions under which infants would be able to exhibit differential responses. The majority of social learning studies which motivated this research used between-subject paradigms (Begus & Southgate, 2012; Koenig & Echols, 2003; Kovacs et al., 2012; Vaish et al., 2011). While the within-subject design is regarded as a golden standard in cognitive psychology studies (by being more robust in light of inter-individual differences and thus affording a more rigorous choice of statistical analyses), it presents a challenge to the social learning and live experimental set-ups. For instance, if the same social partner acts inconsistently from trial to trial, infants may be confused and as a consequence provide indistinguishable responses.

These considerations motivated the decision to utilize both the between- and within-subject designs in study 1, with reliance on the single-experimenter paradigm, although here we asked the caregivers to assume the role of the experimenter. As a result, study 1 allowed drawing important theoretical and methodological conclusions underlying design choices specifically in infants' social learning studies. In studies 2 and 3, we instead chose to recruit participants into a single condition using a two-experimenter paradigm typical for studies of selective social learning with older children (e.g., Koenig et al., 2004; Harris & Corriveau, 2011). The two-experimenter design minimizes the risk of over-interpreting children's responses to a single experimenter, such as assuming that separate conditions are equal on task demands and cognitive processing of the situation. Instead, each participant faces the same contrasting set of choices, e.g., reliable versus unreliable informant, confirming versus counter-intuitive testimony, simple versus complex action demonstration. In studies 2 and 3 we therefore focused on children's responses as they resolved such contradictions. In addition, as very few studies of information transmission exist in children younger

than 3 years of age (Flynn, 2008; Liszkowski et al., 2006, 2008; Vredenburgh et al., 2015), in study 3, we chose to use an existing paradigm (after Vredenburgh et al., 2015), one that introduces children to the ignorant adult learner in a live interaction context, fully benefitting from the two-experimenter paradigm and allowing for rigorous manipulation of the main variables.

V.iii. Choice of outcome measures

The studies in this thesis made use of behavioural measures of social looking (studies 1 and 2) and action demonstration (study 3). Social cognition research has developed a number of distinct yet related measures such as first looks or actions, total frequency or proportion of looks or actions, latency to initiating a look or an action, duration of looks or actions, and length of visual fixations (obtained from eye-tracking data). Bearing in mind that the choice of the exact measure may substantially change the inferences that can be made from a particular set of analyses, we carefully built on the existing literature, considering the rationale for one measure over the other and adopting an approach that a measure on its own is not sufficiently meaningful unless interpreted within the experimental context (for reviews, see Aslin, 2007; Bergmann, Rabagliati, & Tsuji, 2019; Sim & Xu, 2019). For instance, social looks cannot be interpreted as information seeking as such, unless they are selectively generated in situations that afford information gathering, while infants' points cannot be by default interpreted as imperative or informative without taking into account the social context in which they occur. Similarly, longer looking can be interpreted as a response to novelty only within the context of the habituation or as surprise-induced response within the VoE paradigm.

With this in mind, we also explored the relationships between multiple measures rather than inadvertently over-interpreting a single measure (LoBue et al., 2020). With

regards to our study 1 and 2, this is important because previous relevant social learning studies (of infants' social looking responses to referential uncertainty; e.g., Goupil et al., 2016; Vaish et al., 2011; and to VoE, e.g., Dunn & Bremner, 2017; Koenig & Echols, 2003) often used either one or the other measure of infant-generated looks, leaving open the question of which measure indexes which cognitive processes. With regards to our studies 2 and 3, we chose to investigate both the first looks or actions, and the overall proportion of looks or actions as a function of condition, as each is deemed to index a unique kind of response (for a more in-depth discussion of measures used in this thesis, see section IV.iii. of the Discussion Chapter).

Finally, as our measures relied exclusively on offline behavioural coding, to achieve quality data collection we used multiple video cameras to capture the procedure from different angles. In all studies, a minimum of two research assistants were trained to code the data to reach substantial inter-coder reliability.

In sum, this thesis utilized laboratory-based behavioural paradigms providing high ecological validity through involvement of infants' primary caregivers, multiple social partners as unfamiliar and familiar experimenters, and manipulating the properties of information, informants, and the learning context. While cognitively demanding, these studies enabled social contexts which resembled real-life scenarios to provide a unique insight into infants' social and cognitive development.

The following three Experimental Chapters include three journal style papers, which experimentally addressed the three main research questions raised in the Introduction Chapter[2].

[2] The references for the Introduction and Discussion Chapters can be found in the References chapter on page 200. Each Experimental Chapter contains references as part of the individual journal submission.

Experimental Chapter 1: Communication in Epistemic Uncertainty

As curious learners navigating the largely unfamiliar world, infants may encounter situations of epistemic, or knowledge-related, uncertainty. It may take the form of the violation of expectation scenarios which span both physical and social domains, such as events that defy the natural laws of physics or false claims provided by previously reliable people, as well as general informational uncertainty, such as counterintuitive or contradicting testimony, lack of valid and timely information, or being asked questions one cannot answer. Encountering an unexpected or an incongruent event has been shown to elicit distinct neural (e.g., Kouider, Long, Le Stanc, Charron, Fievet, Barbosa, & Gelskov, 2015; Parise & Csibra, 2012; Reid, Hoehl, Grigutsch, Groendahl, Parise, & Striano, 2009) and behavioural responses in infants (Dunn & Bremner, 2017; Goupil et al., 2016; Koenig & Echols, 2003; Harris et al., 2017; Stahl & Feigenson, 2017; Walden et al., 2007).

In addition to enhanced independent exploration following such events, young children solicit input from their social partners (Harris & Lane, 2014; Poulin-Dubois, & Brosseau-Liard, 2016), showing readiness to learn from best information sources (Begus et al., 2016), and actively using communicative cues to obtain information (Begus & Southgate, 2018). As they mature, children are able to utilize a more complex and precise repertoire of independent and social information seeking strategies (Harris et al., 2018). Before showcasing more sophisticated cognition, however, preverbal infants' active communicative responses to epistemic uncertainty help delineate core cognitive competencies underlying epistemic development. This paper focuses on one

of the earliest manifestations of such strategies. How and when do preverbal infants communicate with their social partners when facing epistemic uncertainty?

This chapter contains the first paper which examined the first research question: *Do preverbal infants actively respond to epistemic violations of expectation with social referencing behaviour?*

This paper is currently in preparation for publication:

Bazhydai, M. Westermann, G., & Parise, E. (in preparation). Eleven-month-olds selectively refer to their social partner following epistemic violations of expectation.

Eleven-month-olds selectively refer to their social partner

following epistemic violations of expectation

Marina Bazhydai

Gert Westermann

Eugenio Parise

Contributions

MB, GW and EP designed the study and wrote the manuscript. MB recruited and booked children for the experiment, carried out the experiments, handled and coded the data, and performed all statistical analyses.

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Conflict of interest statement

The authors declare no conflict of interest.

Keywords

- epistemic uncertainty
- violation of expectation
- object-referent mismatch
- social referencing
- infant communication

Research highlights

- Caregivers' incongruent semantic testimony violated infants' epistemic expectations
- Infants selectively referenced caregivers in response to incongruent labels as compared to congruent or no labels
- Social looks increased in inconsistent epistemic environment (a mix of congruent and incongruent labels)
- Social looks index explicit communicative responses to epistemic uncertainty in social contexts

Abstract

Infants' active behavioral responses to epistemic uncertainty is an understudied area in social cognitive development. We investigated the role of social referencing looks as explicit preverbal communicative responses to epistemic uncertainty in social contexts. In two experiments, 11-month-olds infants experienced epistemic violation of expectation events – caregivers providing inaccurate labels to familiar objects. Infants generated more social looks at their caregivers in response to incongruent labels as compared to when labels were accurate or no labels were provided. When caregivers provided a mix of incongruent and congruent labels, social referencing increased following both kinds of labeling testimony as compared to when no labels were provided. Collectively, these results suggest that preverbal infants respond with social looks to epistemic uncertainty induced by receiving incongruent labeling testimony, either consistently or inconsistently, indicating an epistemic function of these communicative behaviors.

Introduction

Infants actively navigate their non-social and social environments, often facing situations of informational (or epistemic, in contrast to emotionally laden) uncertainty, such as when insufficient or unreliable information is provided, or prior knowledge is not supported by new evidence. One powerful scenario that induces epistemic uncertainty in infants is encountering an unexpected event. Little is known about preverbal infants' social behavior in such situations. The current study investigated infants' social referencing as an explicit communicative response to epistemic violation of expectation events (VoE).

Unexpected events provide powerful learning opportunities: violated predictions trigger search for information in order to resolve detected incongruency and improve future predictions (Köster, Kayhan, Langeloh, & Hoehl, 2020). This prediction and error detection process is adaptive as infants seek to update existing mental models of the world or to change models to accommodate new information (Reuter, Borovsky, & Lew-Williams, 2019). A large body of research investigated infants' implicit attention allocation, visual exploration and neural correlates in response to violations of the physical properties of the world (Gliga & Csibra 2009; Stahl & Feigenson, 2019), ambiguous actions (Köster, Langeloh, & Hoehl, 2019; Reid, Hoehl, Grigutsch, Groendahl, Parise, & Striano, 2009) and semantic incongruency (Parise & Csibra, 2012). Unlike infants' implicit detection of uncertainty, less is known about infants' explicit communicative responses when the unexpected event is inherently social and thus induces epistemic uncertainty in the interactive social context.

Similar to selective exploration following VoE events in non-social contexts (in order to disambiguate the causal structure of the encountered event), social communicative responses may help infants probe the social environment for relevant

information to resolve uncertainty through the help of others. Among such early tools is social referencing – initiating social looks at communicative partners to seek social appraisal and guidance (Feinman, 1982; Walden & Ogan, 1988), most often investigated during infants' emotionally laden uncertainty in situations perceived as potentially threatening and necessitating social appraisal input from a trusted social partner to guide infants' own behavior (Campos & Stenberg, 1981; Sorce, Emde, Campos, & Klinnert, 1985; Walle, Reschke, & Knothe, 2017). Recently, social referencing has also been investigated in situations devoid of perceived danger or unpleasantness, such as events violating physical laws or properties of objects (Dunn & Bremner, 2017; Walden, Kim, McCoy, & Karrass, 2007), social pretend play (Nishida & Lillard, 2007), humorous events (Mireault, Crockenberg, Sparrow, Pettinato, Woodard, & Malzac, 2014), uncertain object location (Goupil, Romand-Monnier, & Kouider, 2016), and referential uncertainty (Bazhydai, Westermann, & Parise, 2020; Hembacher, deMayo, & Frank, 2017; Vaish, Demir, & Baldwin, 2011). In all these scenarios, rather than attending to the actual physical source of uncertainty, infants referred to an available social partner. This has been interpreted as infants actively seeking disambiguating cues from someone who can be regarded as a useful source of information (Begus & Southgate, 2018; Harris & Lane, 2014). Do infants also respond with social referencing when their social epistemic expectations are violated?

Studies of infants' responses to intentional object mislabeling by an adult have demonstrated that infants detect object-referent mismatches and pay selective attention to their social partners (Brooker & Poulin-Dubois, 2013; Koenig & Echols, 2003). Sixteen-month-old infants looked significantly longer to the speaker when she mislabeled an object in incongruent trials (as well as at the caregiver who did not participate in any labeling), while instead looking longer at the object rather than the

speaker in congruent trials (Koenig & Echols, 2003). However, when the speaker was facing away from the objects she was labeling, infants looked longer to her in congruent trials, indicating surprise that she was able to label them correctly. Such enhanced attention to the mislabeler was interpreted as indexing a violation of the expectation that social partners are, by default, reliable rather than deceptive informants (Mascaro & Sperber, 2009; Sperber et al., 2010). Extending this seminal finding, Brooker and Poulin-Dubois (2013) showed that 18-month-old infants preferred to learn words from a reliable labeler as opposed to a mislabeler. However, infants in this study initially paid equal attention to both informants, as if first establishing informants' respective informative value, and only at the novel word learning stage looked longer at the previously unreliable informant while selectively learning from the reliable one (see also Crivello, Phillips, & Poulin-Dubois, 2018; Koenig & Woodward, 2010; Krogh-Jespersen & Echols, 2012). In another study using a violation of expectation location change task, 24-month-olds looked longer at the speaker who provided information about object location which was incongruent with the speaker's established knowledge or ignorance state (Galazka, Gredebäck, & Ganea, 2016).

Collectively, these studies suggest that in epistemic uncertainty, infants in their second year evaluate the input from social partners and attend to them selectively based on their established informative value, which ultimately improves their learning outcomes (Nurmsoo, Robinson, & Butterfill, 2010; Poulin-Dubois & Brosseau-Liard, 2016). Importantly, these studies indicate that infants are able to track and respond to two types of epistemic cues in their social environment: object-label correspondence as part of their semantic representations and social partners' epistemic status as part of their social representations. Thus, infants may both respond to the VoE on a local scale (based on situational epistemic value of information, e.g., an incorrect label) and on a

global scale (based on the epistemic profile of the social partner, e.g., a previously unreliable informant). It is unclear how these underlying cognitive processes manifest earlier in development and whether preverbal infants behaviorally respond to semantic and social VoEs in similar ways as older infants. For instance, older children critically evaluate informants' prior accuracy and reliability and make ongoing behavioral adjustments, but evidence is limited as to when this ability for real-time weighting of and flexibility in response to epistemic cues emerges developmentally (Clegg, Kurkul, Corriveau, 2019; Hoicka, Butcher, Malla, & Harris, 2017; Koenig & Woodward, 2010; Leech, Haber, Arunachalam, Kurkul, & Corriveau, 2019; Nurmsoo, & Robinson, 2009; Ronfard & Lane, 2018, 2019).

Whether preverbal infants can only *detect* epistemic uncertainty, or can also use explicit communicative cues to actively *resolve* such uncertainty through the help of their social partners, is an open question. Longer looking at social partners found in the above VoE studies can be interpreted as attention exerted to form epistemic profiles of the available informants (i.e., by encoding their reliability and knowledgeability), as a surprise-induced response to violations of epistemic expectation (i.e., false claims provided by previously reliable people), or as both. Such ambiguity in interpreting infants' looking responses poses a challenge to understanding the underlying cognitive mechanisms (Aslin, 2007; Bergmann, Rabagliati, & Tsuji, 2019; Sim & Xu, 2019). The social context in which the epistemic uncertainty occurs adds an additional layer of complexity to these possible interpretations. With regards to these concerns, Dunn and Bremner (2017) demonstrated that infants' responses to events defying physical laws were better indexed by social referencing than by looking time to the questionable event. In another study, Vaish et al. (2011) measured both the number of social looks and looking time at social partners when infants faced referential uncertainty, albeit

finding inconsistent evidence from these measures. Yet other reports have focused on discrete social looks rather than looking duration as infants' responses to epistemic uncertainty (Bazhydai et al., 2020; Goupil et al., 2016; Hembacher, deMayo, & Frank, 2017; Harris, Bartz, & Rowe, 2017). Overall, then, infants' looking measures can be interpreted in multiple ways that so far have not allowed for assessment of whether looking serves an epistemic function in such scenarios.

In the present study, we addressed the question whether discrete social referencing looks index infants' explicit communicative response to epistemic uncertainty. We presented 11-month-old infants with either congruent or incongruent labeling by their primary caregivers, or no labeling at all, and measured infants' social referencing following such events. We hypothesized that, if available to infants as a communicative tool to probe the social environment for relevant information, social referencing would be enhanced following the VoE events resulting from caregivers' incongruent labeling, whereas detecting no difference in social referencing between uncertainty and no uncertainty conditions may suggest that such looks were not epistemically motivated.

We chose to test 11-month-olds for two reasons. First, we deemed preverbal infants to have the cognitive capacity to initiate social looks motivated by epistemic goals as a developmentally available communicative tool (Bazhydai et al., 2020; Begus & Southgate, 2018; Harris & Lane, 2014). Second, we expected infants of this age to have sufficient receptive vocabulary to understand the presented object-referent stimuli and detect mismatches based on previous work with younger infants (Bergelson & Swingley, 2012, 2018; Parise & Csibra, 2012) and the expected age of acquisition of first nouns (Nelson, 1973). Lastly, as older infants at the age of 16 months have been previously shown to detect semantic incongruency and look longer towards social

partners who enabled it (Koenig & Echols, 2003), testing substantially younger infants is important to trace the origins of selective learning and trust in testimony and delineate cognitive competencies underlying epistemic development (Mills, 2013).

Experiment 1

The goal of Experiment 1 was to test whether infants would selectively generate communicative looks towards their social partners when facing epistemic uncertainty – violations of social (caregiver providing inaccurate information) and semantic (object-referent mismatch) expectation. We employed a between-subject design[3] so that infants consistently experienced either congruent or incongruent labeling events enabled by their primary caregivers, or were assigned to a control condition, where no labels were provided at all, which allowed us to investigate infants' reactions to different levels of epistemic uncertainty (no information vs. incongruent information). We expected to see more social looks occurring in incongruent labeling, followed by no label, with the least during congruent labeling. We chose to involve caregivers rather than unfamiliar adults as labelers to detect the hypothesized effect to the only informant, without an option to look at the caregiver when both the caregiver and an unfamiliar informant are engaged in the experiment (as in Koenig & Echols, 2003).

Experiment 1 methods

Participants

[3] The experimental design was adapted from Parise and Csibra (2012); see also Supplementary Materials for an earlier within-subject version of this design (Experiment S3) which followed the original design more closely but proved less suitable for the social nature of the research question under investigation.

The final sample was 48 11-month-old infants (sixteen in each of three conditions; M_{age} = 331 days, *SD* = 11, range 315-363, 22 girls). Additional eleven infants were excluded for technical errors (*n* = 3), infants' fussiness (*n* = 6), and substantial parental procedural errors (*n* = 2). Participants were recruited from a database of families in the Northwest of England who had agreed to participate in infant studies.

Experimental procedure

Caregivers received instructions during the consenting procedure upon arriving to the laboratory. In the testing room, infants sat in a high chair, with the caregiver positioned slightly behind and to the side of the infant to allow for easy head turns toward them. Both the infants and their caregivers faced a large screen. Caregivers wore an earphone to discreetly receive labeling instructions. The experiment was recorded using a video camera positioned directly in front of the infant's seat.

The experimental sequence is depicted in Figure 1. A trial began by first displaying an occluder together with a visual and auditory attention-grabbing animation (e.g., a rotating star coupled with an exciting sound), during which the caregiver received the labeling phrase via an earphone. The occluder was then removed to reveal an image of a familiar object or animal (one of ten labels and images: apple, banana, ball, book, bunny, car, cat, cup, dog, duck), presented in pseudorandomized order. Upon the image's appearance on the screen, the caregiver said the labeling phrase and pointed to the object on the screen.

Infants were assigned to three between-subject conditions: Congruent (caregiver providing a matching label), Incongruent (caregiver providing a mismatching label), and No label (caregiver not providing a label but instead saying: "Look at this!"). Each infant received up to 10 trials in their respective condition, with each trial lasting 10 seconds to allow ample time for infants to first look at the presented object and then

initiate social looks, while accounting for the time needed for the caregiver to say their respective phrase upon the occluder falling. The experiment lasted, on average, 3.5 minutes. If the infant became distracted, a rotating spiral with a jingle was presented between trials or an interactive break was offered. If the infant became fussy or their attention could no longer be attracted to the screen, the experiment ended before the target 10 trials could be completed.

Measures and coding

We calculated the overall proportion, onset, and duration of social referencing looks toward the caregiver as a function of condition. We chose these three social looking measures in order to disentangle the exact meaning of different types of attention signals as previous research often used discrete number of social looks, accumulated looking time and duration of looks interchangeably. As our hypotheses concerned only the proportion of social referencing measure, we did not predict the pattern of results for the onset and duration measures.

Social referencing was defined as an infant initiating a direct look at a caregiver following the labeling phrase immediately after attending to the object on the screen, consisting of a head turn towards the caregiver and a direct look at their face, but not orienting to the caregiver's body, hands, attempts to touch them, "pick-me-up" gestures or expressing the need to nurse. In instances when the infant initiated more than one look at the caregiver during a trial in this manner, each look was counted, and duration of the looks was summed up for each trial.

In each condition, the proportion of social referencing was calculated as the number of social looks generated in that condition divided by the number of valid trials. The latency to the first social look (onset of social referencing) and total looking time at the caregiver (duration of social referencing) were coded manually from the video

recordings and averaged for each experimental condition. Coding was performed offline from video recordings by a researcher blind to the experimental condition, with a second researcher coding 20% of trials, achieving high reliability (Cronbach's alpha $\alpha = .85$, $p < .001$); all disagreements were resolved through discussion.

Trial exclusions

Infants who completed at least 2 trials were included in the analyses. We excluded trials for three reasons: technical errors ($n = 6$), parental procedural errors ($n = 21$), and infants' fussiness or lack of attention, defined as looking at the screen for less than 1 second overall upon object presentation ($n = 3$). Infants contributed a total of 490 valid trials ($M = 10$, $SD = 0.48$, range 8-12[4]; $n_{congruent} = 161$, $M = 10.06$, $SD = 0.57$, range 9-12; $n_{incongruent} = 161$, $M = 10.06$, $SD = 0.24$, range 10-11; $n_{no\ label} = 158$, $M = 9.9$, $SD = 0.62$, range 8-11).

Experiment 1 results

Forty-seven out of 48 infants used social referencing at least once during the experiment, with 51% of trials containing at least one social look. Infants generated social looks on average 5.6 times across all trials (range 0-14) with a total of 272 social looks coded in the full sample.

A one-way ANOVA was performed with the proportion of social looks generated for Congruent ($M = .45$, $SD = .35$), Incongruent ($M = .73$, $SD = .23$), and No Label ($M = .5$, $SD = .34$) trials (Figure 2a). There was a main effect of condition, $F(2, 45) = 3.82$, $p = .03$, $\eta p^2 = .15$, with homogeneity of variances assumed, Levene's $F = 1.66$, $p = .2$. To disentangle this effect, we ran pairwise independent samples t-tests

[4] Experimenter made exclusion decisions online, so that the immediate replacement trials could be administered aiming to reach 10 target trials. As a result, three infants (one in each condition) received more trials than targeted due to the experimenter failing by accident to stop the procedure on time, with all recorded valid trials included in the final analyses.

accompanied by a Bayes factor analysis (using a default Bayes factor with a wide Cauchy distribution assuming a maximum possible effect size of 0.707, with values below 3 interpreted as insufficient support, 3-10 as moderate support, and 10 and above as substantial support; Jeffreys, 1961), revealing significantly greater proportion of social referencing in Incongruent as compared to Congruent ($t(30) = 2.73$, $p = .01$, 95% CI 0.07 to 0.5, Cohen's $d = .95$, $BF_{10} = 6.6$) and No Label conditions ($t(30) = 2.26$, $p = .03$, 95% CI 0.03 to 0.44, Cohen's $d = .79$, $BF_{10} = 3$), but no differences between Congruent and No Label conditions ($t(30) = -.45$, $p = .66$, 95% CI 0.1 to 0.3, $BF_{01} = 2.1$).

Neither the onset of social referencing ($F(2,45) = .32$, $p = .73$; Levene's $F = 0.47$, $p = .62$) nor the duration ($F(2,45) = 1.03$, $p = .37$; Levene's $F = 1.45$, $p = .64$) showed statistically significant differences in the ANOVAs (Figure 2a).

Experiment 1 discussion

When caregivers mislabeled familiar objects, 11-month-old infants referred to them more than when caregivers properly labeled objects or gave no label at all. These results support the account that infants expect others to provide accurate information – an expectation that is violated by instead receiving incongruent labels (Koenig, Clément, & Harris, 2004; Mills, 2013; Sperber et al., 2010). To respond to epistemic uncertainty, preverbal and pre-pointing infants used social referencing – a communicative tool to seek social input motivated by an epistemic goal, e.g., obtaining relevant and reliable information from a knowledgeable social partner (Bazhydai et al., 2020; Begus & Southgate, 2018; Goupil et al., 2016; Harris, Bartz, & Rowe, 2017; Hembacher, deMayo, & Frank, 2017) – rather than surprise-driven longer looking time at the caregivers as the source of the violation of expectation in this scenario. When no uncertainty was present (both in congruent and no label conditions), infants were less

likely to reference their caregivers, although we expected some level of differentiation between these two varying uncertainty levels situations. Therefore, social referencing bids do not seem to be indicative of active information seeking, since the no label condition did not prompt infants to ask for the labels from their caregivers (and was not different from the congruent condition's level of referencing). Rather, social referencing was a reactive communicative response, selective to the epistemic VoE, which is compatible with our main prediction.

While we detected greater social referencing in response to caregivers' consistently incongruent labeling, the between-subject design of Experiment 1 could not answer if infants responded to the violation of expectation on a local scale (based on the trial-by-trial epistemic value of provided information), or instead on a global scale (based on the established epistemic profile of the social partner). Exposure to a consistent level of epistemic uncertainty in Experiment 1 precludes us from reasoning about infants' ability to flexibly respond to a changing level of uncertainty. If infants expect their social partners to provide accurate information, would they still selectively reference them following an object-referent mismatch in a dynamically changing epistemic environment, where the social partner is sometimes accurate and sometimes is not? In Experiment 2, we tested infants' ability to track epistemic value of information on a trial-by-trial basis and selectivity in their social referencing as they received mixed congruent, incongruent and no labeling.

Experiment 2

We aimed to test whether incongruent labeling by the caregivers in a dynamically changing epistemic environment would selectively elicit infants' greater social referencing as compared to congruent and no label trials. We therefore used the within-subject design retaining the experimental procedure as in Experiment 1, with

some minor adaptations. Greater social referencing in incongruent trials would suggest that infants are not only able to track but also differentially respond to the changing labeling of their caregiver based on the situational epistemic value of information. Alternatively, if infants do not show trial-level differentiation in their social referencing, it would suggest that they respond to the informant's reliability based on their established epistemic profile, such that when caregivers provide mixed labeling testimony, infants' expectations of their inherent reliability would be globally violated.

Experiment 2 methods

Participants

The final sample was 31 11-month-old infants (M_{age} = 332 days, *SD* = 10, range 317-353 days, 11 girls). Three additional infants were excluded due to insufficient number (fewer than 2) of valid trials within each experimental condition (n = 2) and due to general fussiness (n = 1).

Experimental procedure

The procedure was identical to that of Experiment 1 (Figure 1), except that the trial sequence always started with three warm-up congruent trials in order to establish and reinforce the default expectation of the caregiver as an accurate labeler. Following these, the order of trials was pseudorandomized between the three experimental conditions (Congruent, Incongruent, and No Label), so that there were no more than two consecutive trials in the same condition, and no more than two of the same object-label pairs presented consecutively. The experiment lasted 5-7 minutes, with each infant receiving approximately 5 trials in each of the three conditions[5].

[5] Due to the pseudorandomized order of the trials in the sequence, the experimenter adjusted the length of the experiment online, so that the target 5 trials for each condition were met, while ensuring the infant remained attentive, which often resulted in an uneven number of trials in each condition that each infant eventually received.

Measures and coding

The main outcome variables were the proportion, onset, and duration of social referencing. The coding scheme was identical to Experiment 1 and the coders achieved high reliability (Cronbach's alpha $\alpha = .91$, $p < .001$).

Trial exclusions

Following the same criteria as in Experiment 1, a total of 446 trials were included in the final analyses (148 congruent, 152 incongruent, 146 no label) after excluding trials due to technical errors ($n = 7$), parental procedural errors ($n = 23$), and infants' lack of attention or fussiness ($n = 15$). On average, infants completed 14.8 trials ($SD = 3.8$, range 12-26), with five trials in each condition ($M_{\text{congruent}} = 5.29$, $SD = 1.08$, range 4-8; $M_{\text{incongruent}} = 5.25$, $SD = 1.48$, range 2-9; $M_{\text{no label}} = 5.04$, $SD = 1.53$, range 1-8).

Experiment 2 results

Twenty-eight out of 31 infants used social referencing at least once during the experiment. Infants generated social looks on average 9.57 times across trials ($SD = 5.72$; range 3-24), with a total of 233 social looks coded in the full sample, amounting to 53% of valid experimental trials where infants engaged in social referencing.

A repeated-measures ANOVA was performed on the proportion of social looks generated for Congruent ($M = .58$, $SD = .34$), Incongruent ($M = .58$, $SD = .43$), and No Label trials ($M = .42$, $SD = .26$). There was a main effect of Condition, $F(2, 54) = 4.11$, $p = .02$, $\eta_p 2 = .13$; Mauchly's test indicated no violation of sphericity, $x_2(2) = 1.51$, $p = .47$. The post-hoc paired t-test comparison revealed that social referencing was greater in the Congruent as compared to the No Label condition ($t(27) = 2.78$, $p = .01$, 95% CI 0.04 to 0.27, Cohen's $d = .93$, $BF_{10} = 6.7$), the Incongruent as compared to the No Label condition ($t(27) = 2.48$, $p = .02$, 95% CI 0.03 to 0.28, Cohen's $d = .48$, $BF_{10} = 3.7$), but

not different between the Congruent and Incongruent conditions ($t(27) = -0.02$, $p = .98$, 95% CI -0.14 to 0.14, $BF_{01} = 3.87$) (Figure 2b).

Repeated-measures ANOVAs were performed to examine differences in the onset and duration of social looks between conditions, revealing no statistically significant differences (onset: $F(2,54) = 1.24$, $p = .3$, $\eta_p 2 = .04$, with sphericity assumed, Mauchly's test $x_2 (2) = 0.93$, $p = .37$; duration: $F(2,54) = 1.3$, $p = .28$, $\eta_p 2 = .05$, with sphericity assumed, Mauchly's test $x_2 (2) = 0.91$, $p = .31$ (Figure 2b).

Experiment 2 discussion

When infants experienced mixed congruent and incongruent labeling from their caregiver, we did not find evidence for their selective use of social referencing during incongruent trials. We did, however, find diminished social referencing in the no label trials, which suggests that infants processed labeling information on the trial-by-trial basis. While tracking this information locally, infants' communicative response appears to be based on the global epistemic profile of the caregiver rooted in the inherent expectation of their reliability. These results support the account that infants expected their caregivers to provide reliable information, an expectation that was violated by instead receiving interleaved congruent and incongruent labels[6], and therefore responded to this epistemic uncertainty with communicative social referencing looks, in contrast to events when no uncertainty was present (no label condition control trials). Some additional support for the interpretation that infants were able to track the congruency of labeling on a trial-by-trial basis comes from the descriptive results

[6] See also the converging results from the preliminary within-subject Experiment S3 reported in Supplementary Materials also reporting no difference in the social referencing between incongruent and congruent trials, when the no label trials were not introduced to the mix.

showing that the onset of the first social look to the caregiver was substantially (almost a second) faster during incongruent than congruent trials (see Figure 2b). Infants emerge here as intolerant to inconsistency in labeling testimony provided by their caregivers and seeking to resolve this situation through their active communication.

General discussion

The present study was designed to assess whether preverbal infants selectively refer to their social partners when facing epistemic uncertainty. In two experiments, we presented 11-month-old infants with multiple trials when caregivers provided one of three types of information: incongruent, congruent, or no labels for familiar objects. We measured infants' social referencing to test whether they would selectively use it as a communicative behavior upon detecting their incongruent labeling. When the caregiver was repeatedly delivering only one type of labeling testimony, infants preferentially referenced caregivers providing incongruent labels, as compared to those providing congruent or no labels (Experiment 1). When the caregiver was providing mixed labeling testimony, infants preferentially referenced them following both congruent and incongruent labels, as compared to no labels (Experiment 2).

Our research suggests that preverbal infants simultaneously track two types of epistemic cues in their social environment: object-label correspondence as part of their semantic representations, and social partners' epistemic status as part of their social representations. Infants demonstrated their ability to track the changing epistemic value of the information through behavioral adjustment to different levels of epistemic uncertainty (no information in trials with no labels vs. incongruent information, as compared to congruent labels). Despite showing such local sensitivity, infants not only actively referenced their caregivers when they consistently provided incongruent labels (Experiment 1), but also when they provided mixed congruent and incongruent labels

(Experiment 2). These results suggest that infants' social referencing was a response to the violation of expectation stemming from their caregivers providing inaccurate labeling testimony (either consistently or inconsistently), in line with the account that infants expect their caregivers to provide reliable information. When this expectation was violated by caregivers instead providing, at least sometimes, incongruent labels, infants responded with explicit communicative looks. Relatedly, congruent labeling in this scenario may have elicited the same response as incongruent labeling because a violation of expectation of a different kind occurred – that the caregiver provides a congruent label after previous incongruent labeling. In this sense, congruent trials were no different from incongruent ones because epistemic uncertainty during those was primarily related to the informant's epistemic profile rather than the object-referent testimony.

Therefore, our results suggest that infants formed coherent, or global, rather than situational, or local, epistemic profiles of their social partners despite their demonstrated ability to track epistemic cues locally, and this coherent representation could not be easily disrupted in a changing epistemic environment, when mixed cues were provided. In previous studies, similarly, infants showed difficulties when evaluating inconsistent social-moral behavior (Steckler, Woo, & Hamlin, 2017), toddlers were sensitive to consistency in informants' confidence cues (Birch, Akmal, & Frampton, 2010), and older children were less likely to imitate an inconsistent demonstrator who did not "stick to the script" (Herrmann, Legare, Harris, & Whitehouse, 2013).

Alternatively, it is also possible that 11-month-olds may not yet be cognitively able to dynamically adapt their response as the epistemic situation changes, while such selectivity is present in older children who flexibly update their epistemic representations of informants over time, necessitating future research on the

developmental change in this domain (Clegg, Kurkul, Corriveau, 2019; Gillis, Nilsen, & Gevaux, 2019; Hoicka, Butcher, Malla, & Harris, 2017; Koenig & Woodward, 2010; Leech et al., 2019; Nurmsoo & Robinson, 2009; Ronfard & Lane, 2018, 2019). However, even older children need an explicit assessment or a great amount of accumulating evidence of the informant's deception or inaccuracy to overcome the default bias to accept their claims (Fedra & Schmidt, 2019; Krogh-Jespersen & Echols, 2018), despite having the ability to detect incongruency from infancy. Relatedly, a recent study showed that infants, unlike adults, updated their internal model of the dynamically changing visual environment only when necessary, rather than every time a change occurred, which suggests that infants are more open to new, even if immediately unexpected, experience before they choose to modify their predictions (Kayhan, Hunnius, O'Reilly, & Bekkering, 2019). Lastly, as the social partner in our study was always the infant's primary caregiver, future research should investigate whether their global epistemic profile representations are less stable when informants are unfamiliar adults, allowing infants to not only detect errors but also update their social and epistemic beliefs.

Overall, these results go beyond previous reports showing that infants turn to caregivers when events violate their expectations about physical properties of the world (Dunn & Bremner, 2017; Walden et al., 2007), by focusing on social contexts when the source of the violation is the social partner herself. Our results are in line with the general conclusions of the seminal study of infants' response to object-label mismatches by Koenig and Echols (2003), which reported that 16-months-old infants looked longer at an experimenter providing frequent and repeated inaccurate labels over the duration of 30-second trials (as well as the passive caregiver). However, here we focused on social referencing looks as a measure of explicit communication rather than looking

time as an implicit measure of attention towards an event that violated expectations: when a social partner offered unreliable testimony (consistently or at least sometimes), infants not only redirected their attention to them, but also selectively referred to them communicatively.

The present study further underscores the role of social referencing behavior beyond the classical, emotionally driven uncertainty account (Stenberg & Hagekull, 2007; Striano, Vaish, & Benigno, 2006). Recent studies that induced epistemic rather than affective uncertainty suggest that infants initiate social looks as a way to seek missing or disambiguating information (Bazhydai et al., 2020; Goupil et al., 2016; Harris et al., 2017; Mirreault et al., 2014; Stenberg, 2012, 2013; Vaish et al., 2011). Here social referencing may be interpreted as indicative of infants' seeking input to resolve the epistemic conflict and reduce uncertainty through the help of their social partners (similar to adult social appraisal strategies to resolve uncertainty; FeldmanHall & Shenhav, 2019; Walle et al., 2017), possibly even seeking information gain, though our design is unable to directly assess this. What we do clearly show, rather, is infants' selective communicative response in times of epistemic need, which is a reaction (rather than 'interrogative social referencing'; e.g., Bazhydai et al., 2020) to an unexpected input from the social partner. This is in line with the predictive processing account (Köster et al., 2020) and provides insights into the nature of overt behavior rather than attentional or neural mechanisms (Köster et al., 2019; Reid et al., 2009, Parise & Csibra, 2012), with social referencing emerging as one way to reduce or resolve uncertainty when events (caregiver's incongruent or inconsistent labeling) did not comply with the existing predictive mental models.

In sum, the current study deepens our understanding of the cognitive underpinnings and developmental origins of epistemic trust and selective learning

(Harris et al., 2018; Mills, 2013; Ronfard, Bartz, Cheng, Chen, & Harris, 2018). We show that preverbal infants selectively initiate social looks in situations of epistemic uncertainty caused by violations of expectation. Our results further suggest that despite being able to track the changing epistemic value of information, infants communicatively referenced their social partners on the basis of their perceived epistemic profiles: when caregivers provided unreliable (i.e., at least partially incongruent) labeling testimony, infants' expectations of reliability from their trusted social partner were violated. We conclude that social referencing as a communicative response to such globally rather than locally encoded epistemic uncertainty highlights its epistemic function in preverbal infants' social cognitive development.

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Figure 1:

Trial sequence

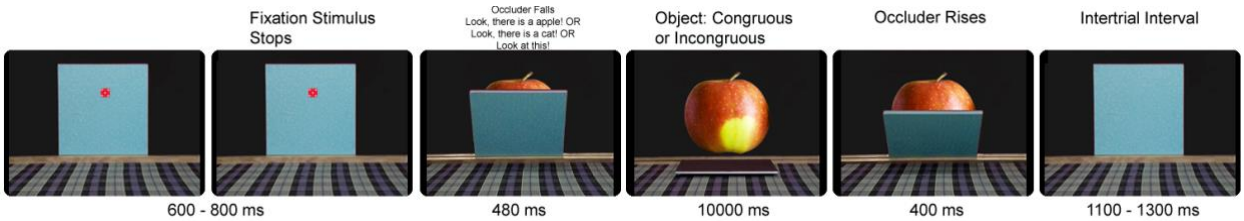


Figure 2:

Proportion, onset and duration of social referencing

Figure 2a: Proportion, onset and duration of social referencing in Incongruent, Congruent and No Label conditions in Experiment 1. The dots represent the distribution of individual values, bold dots represent the mean values, solid lines of the box plots show the median with the first and the third quartiles, the upper and lower whiskers represent scores outside the middle 50%.

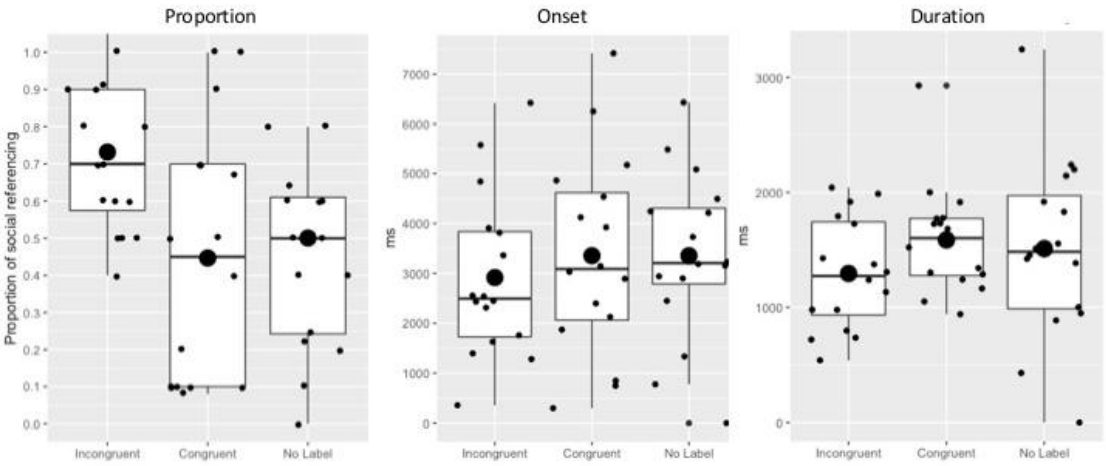
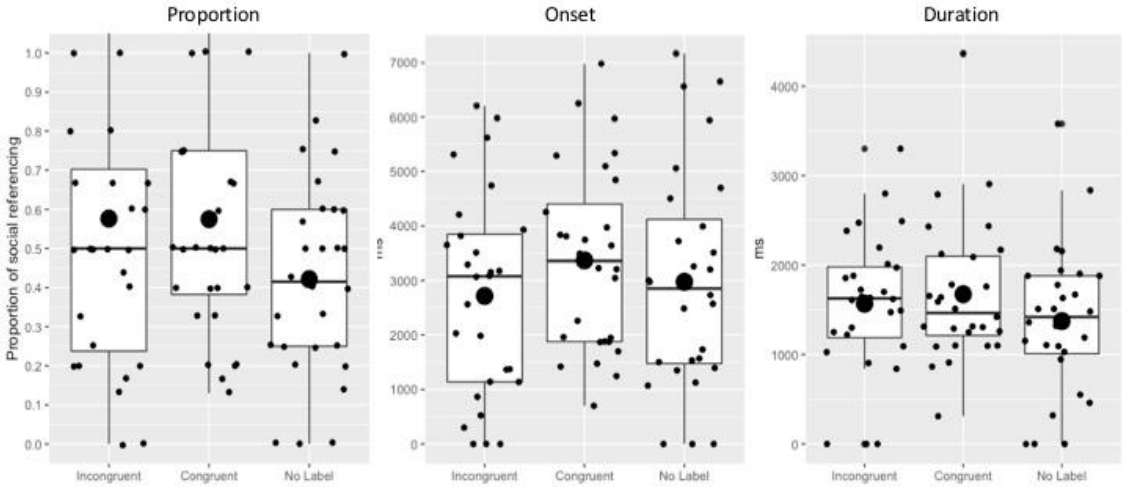


Figure 2b: Proportion, onset and duration of social referencing in Incongruent, Congruent and No Label conditions in Experiment 2. The dots represent the distribution of individual values, bold dots represent the mean values, solid lines of the box plots show the median with the first and the third quartiles, the upper and lower whiskers represent scores outside the middle 50%.



Supplementary materials

Contents

Supplementary analyses: Experiments 1 and 2

Trial-by-trial proportion of social referencing

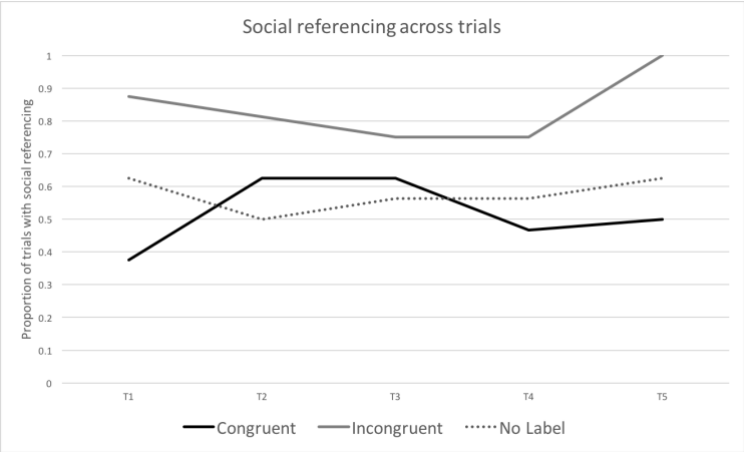
Experiment 1: As the experimental procedure progressed through the initial five trials, infants retained high levels of social referencing in the Incongruent condition and lower levels in the Congruent and No Label conditions (Figure S1a).

Experiment 2: As the experimental procedure progressed for the initial five trials, infants decreased their social referencing in Congruent and No Label trials, but not in Incongruent trials (Figure S1b). This may indicate differential alertness to epistemic uncertainty and enhanced processing of inaccurate information supplied in the incongruent trials, while infants essentially become desensitized to novelty in trials with correct labels or no label prompts. Note, however, that the depicted trial progression is not actually sequential since the order of condition was pseudo-randomized, so this interpretation remains a cautious speculation.

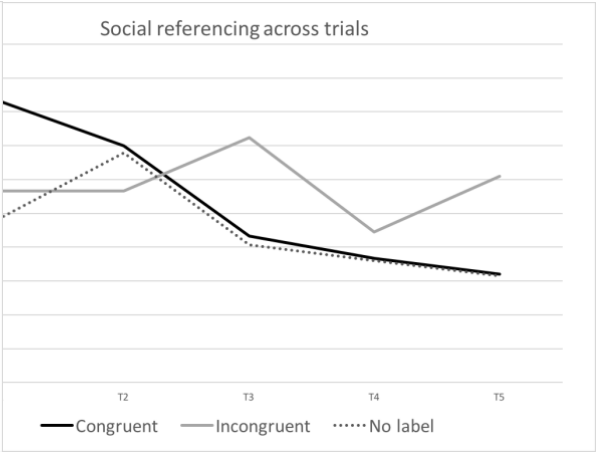
Figure S1:

Proportion of social referencing across first 5 trials of each experimental condition

a) Experiment 1



b) Experiment 2



Caregiver responsivity

The caregivers were instructed to refrain from actively interacting with their child following their utterances while keeping the interaction as natural as possible. Naturally, parental spontaneous reaction to the infant-initiated communicative signals varied. We therefore coded caregivers' contingent responsivity to their infants' social referencing as a control measure for the possibility that caregivers' response differentially affected infants' social referencing. Caregivers' contingent responsivity to the infant-initiated looks was coded when the caregiver returned their child's gaze, smiled or vocalized in response, nodded their head, pointed to the screen while making eye contact with the child, touched or kissed the child, or made any other communicative advances towards the child after their initiated looks. When the caregiver remained neutral and did not engage in any interaction with her child, instead looking at the screen, this was coded as lack of contingent responsivity.

Experiment 1: A one-way 3-factor ANOVA did not reveal statistically significant differences between caregiver responsivity across conditions: Congruent (M = .62, SD = .39), Incongruent (M = .72, SD = .31), No Label (M = .52, SD = .4); $F(1,46)$ = 2.33, p = .13, with homogeneity of variances assumed, Levene's F = 1.41, p = .25.

Experiment 2: A repeated-measures ANOVA did not reveal statistically significant differences between caregiver responsivity across conditions (Congruent M = .72, Incongruent M = .59, No label M = .51, $F(2,54)$ = 2.5, p = .09, with sphericity assumed, Mauchly's test, $x2$ (2) = .93, p = .41).

Experiment S3

This experiment was conducted prior to Experiments 1 and 2 reported in the current paper. We report it here to provide a rationale for methodological considerations which motivated the key changes to the subsequent design, and as complementary evidence for the role of social referencing in response to epistemic uncertainty.

The current experimental study design was adapted from the previous work by Parise and Csibra (2012) which demonstrated early referential understanding of words and a rudimentary receptive vocabulary at 9 months by presenting infants with a series of object-label mismatches and measuring their neural response to semantic incongruency. The original study used event-related potentials (ERPs) to measure the neural signature of semantic mismatch detection, the N400 ERP component. To explore the behavioral manifestations of the labeling mismatch detection, the number of infants' social looks at the person (either caregiver or experimenter) providing labels was also measured, finding no significant differences in response to congruent and incongruent stimuli during the one-second period.

Although Experiment S3 broadly followed the design of Parise and Csibra (2012), we made several important changes. First, we extended the length of object appearance following labeling from 1 second to 7 seconds to provide infants with sufficient time to initiate spontaneous communicative bids, specifically measuring infants' social referencing looks in response to the caregiver's single labeling event (either congruent or incongruent to the object). While in infant ERP research shorter trial duration helps minimize the risk of motion artefacts which are often detrimental to collecting good quality data, behavioral social learning studies in infancy typically employ longer lasting trials. For instance, studies investigating infants' looking response to repeated labeling events had trials lasting between 10 (Brooker & Poulin-

Dubois, 2013) and 30 seconds (e.g., Dunn & Bremner, 2017; Koenig & Echols, 2003). Second, the labeling conditions were always enabled by infants' primary caregivers rather than experimenters.

The goal of the current study was therefore to test whether infants, if given an opportunity and sufficient time, would selectively use explicit communicative cues upon detecting the semantic (object-referent mismatch) and social (object mislabeling by caregiver) violation of expectation. We hypothesized that infants will engage in more social referencing in incongruent as compared to congruent trials.

Experiment S3 methods

Participants

We tested thirty-two 11-month-old infants (Mage = 334 days, SD = 15, range 274-360, 19 girls) from a database of families in the Northwest of England who had agreed to participate in infant studies.

Experimental procedure

Caregivers received instructions during the consenting procedure upon arriving to the laboratory. In the testing room, infants sat in a high chair, with the caregiver positioned slightly behind and to the side of the infant to allow for easy head turns toward them. Caregivers wore headphones to discreetly receive labeling instructions. Both the infants and their caregivers faced a large screen. The experiment was recorded using two video cameras positioned to capture infants' behaviors from different angles: directly in front of and behind the infant's seat.

A trial began by first displaying an occluder together with a visual and auditory attention-grabbing animation (e.g., a rotating star coupled with an exciting sound). In a within-subjects design, a caregiver was instructed to label the anticipated object during the occlusion phase, either congruently (e.g., correctly saying "Look, there is a cat!"

before an image of a cat was revealed) or incongruently (e.g., saying “Look, there is a cat” while an object subsequently revealed was not a cat, but e.g., a duck). The occluder was then removed to reveal an image of a familiar object or animal (one of fifteen labels and images as in Parise & Csibra, 2012). Trial congruency, labels and images of objects were presented in pseudorandomized order. The experiment continued while the infant remained attentive, on average for 7-10 minutes. If the infant became distracted, a rotating spiral with a jingle was presented between trials or an interactive break was offered. The session ended when the infant’s attention could no longer be attracted to the screen.

Measures and coding

We calculated the overall proportion, onset, and duration of social referencing looks toward the caregiver as a function of condition. We chose these three social looking measures in order to disentangle the exact meaning of different types of attention signals as previous research often used discrete number of social looks, accumulated looking time and duration of looks interchangeably. As our hypotheses concerned only the proportion of social referencing measure, we did not predict the pattern of results for the onset and duration measures.

Social referencing was defined as an infant initiating a direct look at the caregiver following the labeling phrase immediately after attending to the object on the screen, consisting of a head turn towards the caregiver and a direct look at their face, but not orienting to the caregiver’s body, hands, attempts to touch them, “pick-me-up” gestures or expressing the need to nurse. In instances when the infant initiated more than one look at the caregiver during a trial in this manner, each look was counted, and duration of the looks was summed up for each trial.

The proportion of social referencing was calculated as the number of social looks generated in each condition divided by the number of respective condition valid trials. The latency to the first social look (onset of social referencing) and total looking time at the caregiver (duration of social referencing) were coded manually from the video recordings and averaged for each experimental condition.

Coding was performed offline from video recordings by two researchers blind to the experimental condition. The second coder coded 20% of trials; all disagreements were resolved through discussion. The coders achieved high reliability (Cronbach's alpha $\alpha = .82$, $p < .001$).

Trial exclusions. To avoid confirmation bias, we made trial-by-trial exclusion decisions prior to coding. Infants who completed at least 2 congruent and 2 incongruent trials were included in the analyses. We excluded trials for four reasons: technical errors ($n = 13$), infants' fussiness ($n = 17$), parental procedural errors ($n = 33$), and infants' lack of attention, defined as looking at the screen for less than 1 second overall upon object presentation ($n = 50$). Infants contributed a total of 575 valid trials ($M = 17.97$, $SD = 6.58$, range 6-31): 286 in congruent ($M = 9$, $SD = 3.28$, range 3-14) and 289 in incongruent ($M = 9.03$, $SD = 3.61$, range 3-17) conditions.

Experiment S3 results

Main analyses included proportion, onset and duration of social referencing; exploratory analyses assessed the role of social referencing occurring prior to labeling.

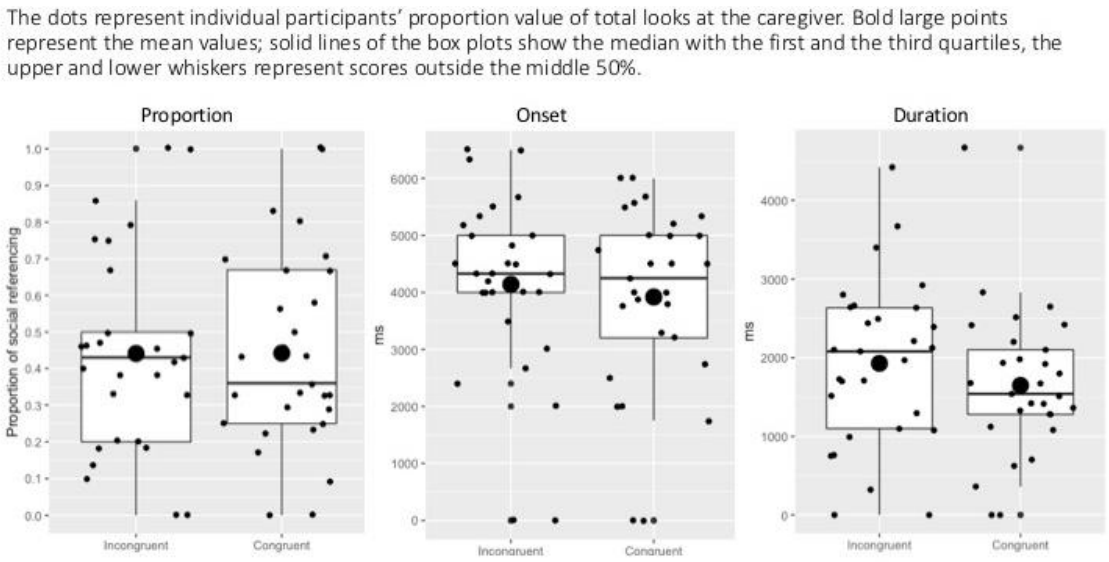
Main analyses

Twenty-nine out of 32 infants used social referencing at least once during the experiment. Each infant generated social looks on average 7.28 times across trials (range 0-21) with a total of 221 social looks coded in the full sample, with 40% of all trials containing at least one social referencing event.

In contrast with our hypothesis, social referencing occurred equally often during congruent (*M* = .44, *SD* = .27) and incongruent (*M* = .44, *SD* = .27) trials, *t*(28) = - 0.17, *p* = .87; BF_{01} = 3.76. The average onset of social referencing (*t*(28) = - 0.61, *p* = .55, BF_{01} = 3.2) and duration (*t*(28) = -1.32, *p* = .20, BF_{01} = 1.7) did not significantly differ between conditions; see Figure S2.

Figure S2:

Proportion, onset and duration of social referencing across conditions



Additional analyses

We coded social referencing to the caregiver which occurred after the spoken label but prior to the object revealed on the screen as a measure of general orientation to the speaker. Twenty-two out of 32 infants looked at their caregiver before seeing the object (*M* = .19, *SD* = .24). On average, infants made 2.78 looks (*SD* = 3.08, range 1-11), with an average length of 1.65 seconds (*SD* = 0.76). After using this measure to baseline-correct the main outcome measure, the main null result of the proportion of social referencing across conditions remained: congruent (*M* = .25, *SD* = .29), incongruent (*M* = .25, *SD* = .35), *t*(28) = 0.05, *p* = .96.

Experiment S3 discussion

The results did not support our prediction that infants will look at their caregiver selectively following incongruent labeling, but are in line what Parise and Csibra (2012) reported in additional behavioural analyses. One possibility is that infants were driven to socially engage their social partners across both conditions, rather than selectively communicate their uncertainty to them and seek epistemic input from them, contrary to the account that preverbal infants would respond selectively in the situation of epistemic uncertainty. However, there are two alternative explanations. It is possible that the current design, due to its manipulation's explicitly social nature, may have been not sensitive to detect differential social referencing.

First, given that infants experienced both congruent and incongruent labeling from the same informant, it is possible that their social referencing was a response to their caregivers' inconsistent epistemic reliability spanning across both types of trials (for similar findings of infants' reactions to inconsistency in social interactions see Steckler, Woo, & Hamlin, 2017). In this sense, the within-subject design did not allow us to delineate whether infants' social referencing indicated non-epistemic interaction seeking (i.e., initiating joint attention), active communicative response to a violation of expectation (e.g., seeking correct label or evidence of relevant social cues, such as that the caregiver is joking), or a response to a low-level uncertainty (i.e., novelty as they saw a new object on the screen in each trial; see Dunn & Bremner, 2017). To disentangle these possibilities, allowing infants to exclusively experience either congruent or incongruent testimony would enable direct comparison of their responses to low-level uncertainty (one that occurs in congruent trials) as opposed to the violation of expectation scenario (incongruent trials). Second, infants may have been additionally confused by the caregiver's labeling when no objects were yet presented on the screen

in the first place, which is supported by large rates of social referencing occurring before the object was revealed. While controlling for the rate of social referencing prior to object appearance did not change the null result in the rate of social referencing after the object-referent mismatch was detected, it is nevertheless possible that infants were confused by the caregiver's premonition-like ability to provide a label, which may have masked the differences in their subsequent communicative social looks.

Both of these concerns were addressed in Experiment 1, where we implemented a between-subject design and changed the onset of caregiver's labeling to occur after the object's appearance rather than before. Experiment S3 therefore served as a pilot which allowed us to optimize the procedure for measuring social referencing behavior in Experiments 1 and 2 reported in the main body of the paper.

Experimental Chapter 2: Information Seeking in Epistemic Uncertainty

The previous chapter presented an experimental investigation of the role of social referencing in epistemic uncertainty, demonstrating that preverbal infants use social referencing as an active communicative cue when they face epistemic, as distinct from emotional, uncertainty, therefore suggesting an epistemic function of this behaviour. Social referencing was selective in the epistemic violation of expectation situation, specifically when the infant's caregiver provided inaccurate labels to familiar objects. The results suggest that infants detected the object-referent mismatch and expected their caregivers to provide congruent semantic information – an expectation violated by instead receiving incongruent labels.

Preverbal infants emerged as active participants in the social information exchange process, using their developmentally available communicative tools to engage in social interaction. While this study design does not provide a direct insight into the specific meaning of social referencing looks, the results suggest that such looks, as opposed to passive preferential looking time measures, are active and communicative in nature. Infants may have been seeking disambiguating or clarifying information to reduce uncertainty associated with an incongruent label or to verify the communicative cues of the mislabelling caregiver to clarify their intentions. For instance, infants may have intended to verify their access to information (i.e., "Is she looking at the right object?") or check their facial expressions or other pragmatic cues that may be relevant to the information provided (i.e., "Is she playing a game with me?"). This reasoning is in line with previous reports of children's responses to a testimony from a blindfolded

informant (Nurmsoo & Robinson, 2009) or a speaker facing away from the source of information (Koenig & Echols, 2003). Overall, as a communicative signal following uncertainty detection, the social referencing pattern in the present study lends support to infants' propensity to communicate with others during uncertainty, supposedly with an epistemic goal of obtaining relevant and reliable information from trustworthy social partners (for similar reasoning, see also Goupil et al., 2016; Harris et al., 2017; Hembacher et al., 2017).

The second study in this thesis aimed to further characterise the role of preverbal infants' communication in epistemic uncertainty. Here, infants faced a different kind of uncertainty (about the novel object's referent) and had an opportunity to seek specific information from available social partners. We asked whether social referencing as an active communicative behaviour can be used by infants to seek epistemic information, and to do so from the best available source of information – a previously reliable rather than ignorant informant.

The epistemic uncertainty with which infants faced here also unfolded in a social context, but was more complicated than the previous study: in addition to their primary caregivers, infants also interacted with two unfamiliar adults. The caregivers were asked to enable epistemic uncertainty by posing a question to which neither themselves nor their children had or could independently obtain an answer. However, the infants had a choice of two potential social partners, differing in their projected epistemic status, to whom they could refer in search of an answer. Previous research demonstrated that infants are sensitive to indices of plausibility, congruency and validity in the information they obtain about the world and in the social partners who supply information (Harris, 2012; Stahl & Feigenson, 2019). Such epistemic sensitivity in social contexts plays an important role in infants' interaction with unfamiliar adults;

while primary caregivers may be perceived as truthful and reliable by default, infants have to establish an appropriate epistemic status of unfamiliar informants (Harris, 2019; Sperber et al., 2010). We tested the role of infants' social referencing as information seeking communicative signals in a more complex, but also more ecologically valid situation of uncertainty when multiple sources of information are available.

This chapter contains the second paper in this journal format thesis, which examines the second research question: D*o preverbal infants use social referencing to seek information from more knowledgeable adults in a situation of referential uncertainty?*

This paper has been published in the same format as presented in this thesis:

Bazhydai, M., Westermann, G., & Parise, E. (2020). "I don't know but I know who to ask": 12-month-olds actively seek information from knowledgeable adults. *Developmental Science.* doi:10.1111/desc.12938

"I don't know but I know who to ask":

12-month-olds actively seek information from knowledgeable adults

Marina Bazhydai

Gert Westermann

Eugenio Parise

Author Contributions

MB, GW and EP conceived and designed the study and wrote the manuscript. MB collected and analyzed the data.

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Declaration of Conflicting Interests

The author(s) declared that there were no conflicts of interest with respect to the authorship or the publication of this article.

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Open Practices Statement

The data that support the findings of this study are openly available at the Open Science Framework [https://osf.io/dj9cn/?view_only=72b0e95b5ab144cc85ab07f8a04839f2]; the study was not formally preregistered.

Keywords:

- information seeking
- social referencing
- referential uncertainty
- active social learning
- epistemic knowledge
- knowledge transmission

Research highlights

- 12-month-olds reliably assessed the informative potential of the available social partners and selectively queried the best source only when information was needed.
- Preverbal infants used social referencing to actively and selectively seek information from social partners as part of their interrogative communicative toolkit.
- Social referencing served as a communicative means to seek epistemic rather than emotionally laden information in the situation of referential uncertainty.
- Results indicate that infants actively participate in the cultural interpersonal process of knowledge transmission, using basic nonverbal communicative tools at their disposal.

Abstract

Active social communication is an effective way for infants to learn about the world. Do preverbal and pre-pointing infants seek epistemic information from their social partners when motivated to obtain information they cannot discover independently? The present study investigated whether 12-month-olds (N = 30) selectively seek information from knowledgeable adults in situations of referential uncertainty. In a live experiment, infants were introduced to two unfamiliar adults, an Informant (reliably labeling objects) and a Non-Informant (equally socially engaging, but ignorant about object labels). At test, infants were asked to make an impossible choice - locate a novel referent among two novel objects. When facing epistemic uncertainty – but not at other phases of the procedure - infants selectively referred to the Informant rather than the Non-Informant. These results show that preverbal infants use social referencing to actively and selectively seek information from social partners as part of their interrogative communicative toolkit.

Introduction

Infants are notoriously curious and active learners. To enable effective knowledge acquisition, they actively seek information in both independent and social learning contexts (Begus & Southgate, 2018; Oudeyer & Smith, 2016). Recent research has begun to investigate infants' ability to judge their social partners' suitability to provide relevant information and selectively seek it from the most suitable informant (Harris, Koenig, Corriveau, & Jaswal, 2018). Nevertheless, early developmental manifestations of active information seeking are poorly understood. Here we investigate the developmental origins of intentional communication soliciting information in social learning by asking whether and how preverbal and pre-pointing infants actively and selectively refer to others in situations of epistemic uncertainty.

Infants' selective attention and active exploration of their environment has been investigated both in non-social contexts, highlighting infants' independent discovery-oriented behaviors that optimize their learning outcomes (Gottlieb, Oudeyer, Lopes, & Baranes, 2013; Kidd & Hayden, 2015), and in social learning contexts. Beginning in their first year of life, infants are capable to quickly and accurately form situational epistemic profiles of their social partners based on a variety of cues (Poulin-Dubois & Brosseau-Liard, 2016), such as the social partner's competence (Begus & Southgate, 2012; Begus, Gliga, & Southgate, 2016), reliability (Crivello, Phillips, & Poulin-Dubois, 2017; Tummeltshammer, Wu, Sobel, & Kirkham, 2014), credibility (Birch, Akmal, & Frampton, 2010), and confidence (Brosseau-Liard & Poulin-Dubois, 2014). In sum, infants show vigilance towards and keen understanding of knowledge distribution among social partners. However, little is known about whether preverbal infants actively, spontaneously and strategically seek information in social contexts. Do

infants possess the communicative means to query others for epistemic information even before being able to formulate questions verbally?

Active social communication is an effective way for infants to learn about the world. In addition to supporting their social and emotional needs, one early communicative signal – pointing - has been proposed to serve an interrogative, or information seeking function (Harris & Lane, 2014; Southgate, Van Maanen, & Csibra, 2007), endorsing the idea that pointing holds a special place as a cognitive milestone (Tomasello, Carpenter, & Liszkowski, 2007) in that it enables infants to take an active interrogative stance which is not available to them earlier in development. Specifically, pointing has been demonstrated to be a unique communicative tool used selectively in the presence of an informative social partner emerging in the second year of life (Begus & Southgate, 2012, at 16 months; Kovács, Tauzin, Téglás, Gergely, & Csibra, 2014, at 12 months; Lucca & Wilbourn, 2018, at 18 months).

Several crucial insights about interrogative communication in infancy have been gained from this line of research: infants are capable of recognizing the informative potential of their social partners and, when motor development allows it, can use pointing gestures to interrogate them. However, to our knowledge, no studies of infants' interrogative pointing have shown whether requesting information is selective from a specific source, such as demonstrating that infants point to a knowledgeable person when competing sources of information are available. All previous studies employed a between-subject design in which an infant encountered a single experimenter, and they have focused on very specific aspects of information provision. For example, in the seminal interrogative pointing study (Begus & Southgate, 2012), one group of infants interacted with an informant providing correct object labels, and a second group with an informant providing false labels. In another study (Kovács et al., 2014, Experiment

1), infants either interacted with an adult who showed varied emotional response or expressed positive interest, or provided either a familiar or a novel label (Kovács et al., 2014, Experiment 2). The general cognitive mechanism specifying if and how infants select an information source from a set of options remains unknown.

While pointing has been the primary focus of attention in this line of investigation, other preverbal behaviors emerge prior to pointing which could serve the same functional mechanisms or act as a cognitive prerequisite for interrogative communication (Begus & Southgate, 2018; Ronfard, Zambrana, Hermansen, & Kelemen, 2018). One of them is social referencing, defined as initiating a look at a social partner in order to obtain situational information which may help guide behavioral choices (Walden & Ogan, 1988). Social referencing has been primarily used to show how infants resolve situations of emotional uncertainty by assessing the affective response of their caregiver or another adult to aversive, unsettling or potentially dangerous events, such as approaching a perceptual drop-off (Campos & Stenberg, 1981; Sorce, Emde, Campos, & Klinnert, 1985). Having been initially linked to indices of attachment and comfort seeking (Stenberg & Hagekull, 2007; Striano, Vaish, & Benigno, 2006), social referencing has been established as a behavior specifically eliciting social appraisal information - albeit only in emotional contexts. In utilizing this behavior, infants are sensitive to adults' manifested expertise and competence cues in selectively choosing who to refer to in order to resolve their emotionally-laden uncertainty (Schieler, Koenig, & Buttelmann, 2018; Stenberg, 2009, 2013).

While adults serve as a point of reference for infants in uncertain situations, similar to other sources of information (both passive non-social and active social), such initiation of a social referencing look at an adult can be interpreted as an active

communicative act of asking them for information – a request for input, an "interrogative social referencing", aimed at not only expecting but actively eliciting a response from a social partner from whom they wish to obtain information. In this sense, social referencing, like pointing, may be a proto-interrogative requestive act of a specific kind which functions to "induce the manifestation of some knowledge from the willing adult" (Southgate et al., 2007, p .738).

Do preverbal infants also use social referencing to actively and selectively seek epistemic information? Recent research has gone beyond studying social referencing exclusively in emotional contexts, challenging the long-standing view that it evolved for socio-emotional engagement purposes only, that it is not fully social until the second year of an infant's life, and that infants are not capable of intentional information seeking at this age (Baldwin & Moses, 1996). Several reports showed that infants also use social referencing in non-emotional uncertainty, such as when their expectations are violated (Dunn & Bremner, 2016; Walden, Kim, McCoy, & Karrass, 2007), when they are presented with referential ambiguity such as two novel objects and only one novel label (Hembacher, deMayo, Frank, 2017; Vaish, Demir, & Baldwin, 2011), and when they know they can obtain information from a social partner about the location of hidden objects (Goupil, Romand-Monnier, & Kouider, 2016). But none of the previous studies of social referencing demonstrated whether infants go beyond appreciation of informative potential of social partners, and are able to query the best available source when in need of specific information.

A small number of studies suggest that social referencing is an active communicative behavior allowing preverbal infants to resolve epistemic uncertainty in social learning contexts. For example, Vaish et al (2011) demonstrated that infants at 13 months sought disambiguating referential gaze from an adult in a labeling

uncertainty situation. At 16 months, infants referred to their social partner while signaling their ignorance when they did not know the name of the novel item (Harris, Bartz, & Rowe, 2017). Goupil et al (2016) showed that 20-month-olds' increased social referencing to their caregiver to solicit help locating a hidden object. Here, we propose that social referencing enables them to not only selectively seek epistemic information from an appropriate source, but to do so specifically when needed. We chose to study this process in 12-month-olds and in a word learning context. Infants at the end of their first year are active word-learners with a mean receptive vocabulary of around 80 words (Frank, Braginsky, Yurovsky, & Marchman, 2017) and we here capitalize on their active interest in learning new words (Mani & Ackermann, 2018).

We developed a novel experimental paradigm that invites 12-months-olds' active and spontaneous search for epistemic information from social partners, where social referencing is an available communicative tool to ask for help from either a knowledgeable (Informant) or an ignorant adult (Non-Informant). Building on the findings from interrogative pointing and social referencing research, we aimed at eliciting infants' spontaneous, rather than experimentally trained, social referencing looks in a dynamic social interaction. Infants met two new adults who contrasted in their ability to provide specific information (a label) while remaining equally engaging and sociable. We predicted that infants would show selectivity based on the established informative potential of their social partners, using social referencing with the intention to gain specific information when needed. Our goal was to understand infants' developing ability and cognitive prerequisites to interrogating informants in order to resolve a situation of epistemic uncertainty.

Method

Participants

The final sample consisted of 30 1-year-old infants (14 boys, *M* = 368 days, *SD* = 17, range 340 to 404 days). With a power of 0.80 and alpha of 0.05, a sample size of 29 is sufficient to produce a large effect size (G*Power analysis software, Faul, Erdfelder, Lang, & Buchner, 2007). Twelve additional infants were tested but not included due to unwillingness to participate in the procedure (N = 9) or substantial parental procedural interference (N = 3).

Equipment

Two video cameras captured the scene from two different angles. We used a head-mounted eye-tracker (Positive Science) to record infants' gaze direction (PSLiveCapture, v1.8.3). We used Yarbus (v2.2.9) for offline calibration and GazeTag (v0.94) for post gaze processing. Parents and experimenters could follow timing and instructions of the experimental procedure on a prompts screen displaying a Power Point presentation.

Stimuli

Three familiar toys (ball, banana and book) and two novel objects were used during the familiarization trials, two familiar toys (duck and fish) during the warm-up training trials, and six pairs of novel objects during the test trials. All objects were brightly colored, and pairs were selected based on perceptual similarity (see Figure 1a).

Procedure

A researcher not involved in the experimental procedure completed parental consent and training on the procedure, played with the infant and brought them to the testing room. There, the infant was first introduced to two unfamiliar experimenters, and then sat in a high chair at the short end of a rectangular table. The researcher mounted the eye-tracker on the infant's head, engaged the infant in warm-up play, and performed the calibration procedure with two familiar objects. The two experimenters

(Informant and Non-Informant) sat at the long ends of the table across from each other, with sides counterbalanced across participants. The caregiver was positioned across the table from the infant, facing the prompts screen, while the researcher remained behind the infant (Figure 1b).

Experimental procedure

The procedure (Figure 1c) involved a familiarization phase, followed by a warm up training trial and a test phase.

Familiarization

There were four familiarization trials, each lasting 25 seconds, two with familiar objects and two with novel objects. A reinforcement trial, identical to familiarization trials with familiar objects, was presented later on, following the first test trial. This trial was introduced after piloting in order to ensure infants' sustained attention on the procedure for the remaining five test trials and it is not used for main statistical analyses (but see Supplementary Materials for these data).

On each familiarization trial the caregiver retrieved one of the 3 familiar objects (Trials 1 and 2, later labeled by the Informant as *ball, banana,* and *book)* or one of the 2 novel objects (Trials 3 and 4, labeled by the Informant as *dani* and *fifa*) from a tray below the table (Figure 1a) and placed it on the table out of the infant's reach. Upon placing the object, the caregiver asked "What is this?". Following the caregiver's question, both the Informant and the Non-Informant established joint attention with the infant, making direct eye-contact, smiling, and speaking in child-directed intonation. Either the Informant or the Non-Informant spoke first, counterbalanced across trials. The Non-Informant said: "I don't know!", whereas the Informant provided the label as she pointed to the object: "This is a [label]!". The caregiver then pushed the toy closer to the infant for a 20-second object exploration, during which the Informant and the

Non-Informant continued with their respective utterances as described below. The Informant labeled the object 4-6 times, using utterances such as “Look, this is a ball!”; “Wow, a ball!”; “What a nice ball!”; “I like this ball!”, “Where is the ball?”, “A ball!”. The Non-Informant provided a positive, engaging social interaction, using 4-6 utterances such as “Look at this!”; “Oh Wow!”; “What is this?”; “Hmm...”; “This is nice!”; “I like this!” Both experimenters naturally took turns speaking to the infant, taking care to not interrupt each other.

Warm-up training

The single warm-up training commenced a substantial change in the procedure and was designed specifically to introduce and ease infants to the change in the object presentation routine after the familiarization trials: here, infants were not provided an opportunity to explore presented toys immediately. This trial (and the subsequent test trials) consisted of the following episodes: object presentation, information seeking, information provision, object exploration, and object choice (Figure 1d).

During the warm-up training trial, two familiar objects, a *duck* and a *fish,* were placed by the caregiver out of the infant’s reach, with the caregiver asking: “Which one is the duck?”. After a period of 15 seconds, during which all adults remained silent and looked at the infant, the caregiver repeated the question. During this period the infant could seek information by looking at the experimenters. In the next, “information provision” episode, the Informant responded with the correct label (“This one is the duck!”), simultaneously pointing to the duck toy, while the Non-Informant expressed ignorance about the label (“Oh wow! Is it?” or “I don’t know!”), just as she did during the familiarization phase, with the order of who spoke first counterbalanced as during familiarization. Following the experimenters’ respective utterances, the caregiver placed both objects in front of the child for a 20-second exploration.

Test

The test trials' procedure was identical to the warm-up training trial except that the infant now was presented with two novel objects and inducing high referential uncertainty ("Which one is the [pseudoword]?") (Figure 1d). The caregiver did not know the novel objects' labels. Following the infant's opportunity to seek information, the Informant (either speaking first or after the Non-Informant's utterance) pointed to and labeled one of the objects with the pseudoword in question, consistently labeling the same pre-selected object in each of the pairs. There were six test trials; the first test trial followed the warm-up training trial, and the remaining five test trials followed the reinforcement familiarization trial which was identical to the familiarization trials (Figure 1c).

Trial exclusion criteria

For behavioral data analyses, 99% (N = 119) of familiarization, 73% (N = 22) of training, and 87% (N = 143) of test trials were included. Infants completed on average 5.4 test trials, with 4.8 valid trials retained for analyses. Trials were excluded due to infant fussiness or refusal to take part in the procedure (N = 10), experimenter error (N = 8), caregiver procedural interference (N = 4), and technical problems (N = 4). As expected by design, the warm-up training trials were excluded most often due to infant fussiness resulting from not having access to the toys immediately and due to caregiver mistakes following a change in the procedure. As a result, only 22 (out of 30) warm-up training trials were available for analyses.

For the head-mounted eye-tracking based data analyses of the length of visual fixations, we obtained a limited dataset comprised of 20 infants for familiarization, 10 for training, and 15 for test trials. This was due to low tolerance of wearing the equipment, as well as pulling the eye-tracker off in the middle of the experimental

procedure, e.g., after the familiarization trials when they were facing silent periods during the warm-up training or test trials' "opportunity to seek information" episodes. We therefore had a restricted sample available for analyses of the length of infants' visual fixations and consider such analyses supplementary to the main behavioral social looks analyses. Nevertheless, these analyses were instrumental for comparison of the number of looks and the total looking durations as two distinct measures.

Coding

We were interested in determining how much attention infants directed at each experimenter in all phases of the procedure, measured by first looks, total looks, and the duration of the looks. We distinguish these measures from a functional standpoint. For the familiarization trials, we used the video recordings to code the number of looks at each experimenter and the eye-tracker to code the length of visual fixations on each experimenter. We calculated a proportion of looks at the Informant and the Non-Informant out of the total looks infants made at the two experimenters during the familiarization phase, averaging across four trials. This measure indexes infants' attention as they encoded the experimenters' epistemic profiles. We also coded infants' first looks at this phase. However, as infants' initial attention was expected by design to be directed at whoever spoke first on each trial, the function of infants' first looks is inevitably different from the function of the first looks during the warm up and test trials when infants were facing uncertainty and nobody was speaking for 15 seconds (Figure 1d).

For both the warm-up training and the test trials, we coded first looks, total number of looks averaged across six trials (from the video recordings), and length of infants' visual fixations (from the eye-tracker) at each experimenter during the 15-second-long "opportunity to seek information" episode. Here, the hypothesized

function of looks is to solicit information from the experimenters as opposed to attend to their information provision as during familiarization.

Of note, further, are the functional differences between the measures of duration of looks and the discrete social looks. It has been debated what looking time preferences mean (Aslin, 2007; Sim & Xu, 2019) and whether looking time and social looks index the same cognitive mechanisms (Dunn & Bremner, 2017; Haith, 1998; Walden et al., 2007). The exact measure of social looking as epistemic information seeking is a topic of ongoing investigation as both the number of social looks and the duration of social looks have been previously used as a primary outcome measure (e.g., Koenig & Echols, 2003; Vaish et al., 2011). Here we focused on the number of discrete social looks as an index of information seeking and the looking duration as an index of information encoding.

Two independently trained research assistants coded 100% of the behavioral data, achieving substantial agreement (Landis & Koch, 1977) for the first looks (Cohen's kappa κ =.78, $p < .001$) and excellent agreement for the total looks coding (Cronbach's alpha $\alpha = .92$, $p < .001$); all disagreements were resolved through discussion. The main coders were not blind to the identity of the experimenters. A subset (20%) of test trials was also coded by a coder blind both to the hypotheses and the identity of the experimenters, achieving excellent reliability both for first looks (κ = .90, $p < .001$) and for total looks ($\alpha = .94$, $p < .001$).

Results

The results of infants' social looks at the Informant and the Non-Informant are presented separately for the familiarization, warm-up training and test trials, followed by the cross-phase comparisons and regression analyses. Exploratory analyses and additional figures are available in the Supplementary Materials. A Bayes Factor analysis

was performed to determine the probability of the null or the alternative hypothesis being true (i.e., that there is no difference between looks at the Informant and the Non-Informant or that there is a difference) given the data (Jeffreys, 1961). For all analyses, we used a default Bayes factor (Rouder et al., 2012) with a half normal distribution (assuming a maximum possible effect size of 0.707).

Familiarization

Averaged across four trials, infants' looks at the Informant were at chance for first looks (M = .56, SD = .24, $t(29) = 1.35$, p = .1, one-sample t-test; BF_{01} = 1.7; Figure S1) and total looks (M = .51, SD = .12, $t(29) = .64$, p = .53, BF_{01} = 3.28; Figure 2a), and there were no differences between length of visual fixations on the Informant (M = 284, SD = 230 ms) and the Non-Informant (M = 264, SD = 385 ms), $t(19) = .23$, p = .82, paired t-test; BF_{01} = 3.2.

Warm-up training

The proportion of looks at the Informant was at chance for first looks (M = .50, SD = .51, $t(21) = 0$, p = 1, BF_{01} = 4.48), total looks (M = .42, SD = .42, $t(21) = -.91$, p = .37; BF_{01} = 4) and length of visual fixations (Informant M = 303, SD = 548 ms, Non-Informant M = 171, SD = 224 ms; $t(9) = .67$, p = .52; BF_{01} = 2), Figure S2.

Test

Infants were significantly more likely, on average during six trials, to first reference the Informant rather than the Non-Informant, M = .69, SD = .30; $t(29) = 3.34$, p = .002, 95% CI (.07, .30), Cohen's d = .63, one-sample t-test; 21 out of 30 infants looked at the Informant first, Wilcoxon Signed Ranks test z = -2.8, p = .005. Bayes Factor Analysis yielded a BF_{10} = 23, strongly supporting the alternative hypothesis and thus corroborating the result obtained with the frequentist statistics. The proportion of total looks at the Informant was significantly higher than the proportion of total looks

at the Non-Informant, M = .65, SD = .24; $t(29)$ = 3.43, p = .002, 95% CI (.12, .48), Cohen's d = .63, BF_{10} = 28, with 22 out of 30 infants showing the effect, Wilcoxon Signed test z = -3.14, p = .002 (Figure 2a). Infants' visual fixations were significantly longer for looks at the Informant (M = 253, SD = 160 ms) than at the Non-Informant (M = 134, SD = 83 ms), $t(14)$ = 2.41, p = .03, 95% CI (12.98, 224.49), Cohen's d = .62; z = -2.05, p = .04; BF_{10} = 3.2.

Cross-phase comparisons

To clarify whether infants preferentially looked at the Informant only when a situation of epistemic uncertainty warranted further information seeking (as during the test phase's opportunity to seek information episode), instead of preferentially looking in appreciation of the Informant's knowledge overall (as during the familiarization phase), we conducted the following cross-phase comparisons. We compared total looks and length of fixations between familiarization and test phases. The cross-phase comparison of first looks is reported in Supplementary Materials, Figure S1, due to the distinctions in functional meaning between first looks at different phases (familiarization: first look at whoever speaks first; test: first look at whoever can help resolve epistemic uncertainty).

Total looks. The proportion of infants' total looks at the Informant was significantly higher during the test phase as compared to the familiarization phase, $t(29)$ = - 2.91, p = .007, 95% CI (-.23, -.04), Cohen's d = .55, BF_{10} = 8.9 (Figure 2b). To follow up on this comparison more specifically, we selected two familiarization and two test trials, which differed on whether or not the infant was facing referential uncertainty when presented with equally novel toys. The average proportion of infants' total looks to the Informant during the last two familiarization trials (where the caregiver presented novel toys without asking the infant for the objects' names) was significantly

lower than the proportion of total looks to the Informant during the first two test trials (where the caregiver also presented novel toys but now asked the infant to identify a label in a pair of two novel toys), $t(29) = 3.39$, $p = .002$, 95% CI (.09, .37), Cohen's $d = .53$, $BF_{10} = 26$ (Figure 2b).

Length of fixations. Infants did not spend significantly longer fixating on the Informant during the test phase as compared to the familiarization phase, $t(14) = .94$, $p = .36$, $BF_{01} = 1.95$.

Regression analyses. To test whether infants' looks at test were influenced by their looks at familiarization, we fitted two linear regression models. The proportion of infants' first looks towards the Informant generated at familiarization was not predictive of their preferential first looks at the Informant at test ($\beta = .03$, $t(28) = .16$, $p = .88$), and there was no effect of the total looks in the familiarization phase on total looks at test ($\beta = .25$, $t(28) = .68$, $p = .50$).

Discussion

To understand preverbal infants' active role in social transmission of knowledge, we introduced 12-months-olds to two unfamiliar adults, an Informant and a Non-Informant. At test, in a situation of referential uncertainty, it was impossible for infants to independently discover the missing information (a novel label's actual referent), but they could seek it from available social partners. Infants selectively referred to the previously knowledgeable rather than an equally socially engaging but ignorant adult. Infants showed no such preference at other phases where they did not require information, providing strong evidence that their social referencing was selective and served an information seeking function (see Supplementary Materials for additional control analyses). We conclude that infants were able to reliably assess the

informative potential of the available social partners and selectively queried the best source when information was needed.

In line with our hypothesis, these results demonstrate that social referencing serves as a communicative means to solicit epistemic knowledge from others. While there is convincing evidence that interrogative pointing (where infants request information about an object by pointing at it, e.g., Begus & Southgate, 2012; Kovács et al., 2014; Lucca & Wilbourn, 2016; 2018) indexes infants' ability to pose epistemic requests (Southgate et al., 2007; Tomasello et al., 2007), we find that infants are cognitively ready to do so by use of social referencing, which overall emerges earlier in development and is available to pre-pointing infants. In our new paradigm we actively elicited a different behavior, where information was sought by specifying the informant rather than the referent. While our results do not speak to whether interrogative social referencing is a developmental precursor to interrogative pointing or emerges independently, the current study highlights the early emerging cognitive mechanisms enabling epistemic interrogation. One way to interpret these social looks is as intentional communicative acts *triggering* epistemic help from cooperative and interactive social partners, in contrast to merely gathering information from a passive source such as a book. However, to further delineate whether infants actually posed epistemic requests (as in interrogative pointing) with their social looks, we would require clear evidence that they would persist in their communicative attempts triggering information elicitation, such as repeated pointing or vocalizations when their initial requests are not responded to (Southgate et al., 2007; Tomasello et al., 2007). Some data from our study supports such an interpretation: as experimenters remained unresponsive during the "opportunity to seek information" episode, infants continued to generate repeated social looks as if they were not satisfied with a lack of answers and

thus continued to demonstrate their interest in obtaining a response. Designing an experimental situation to specifically answer this question is an important future step in this line of research.

Previously, selectivity in social referencing in ambiguous situations has been most commonly attributed to gathering emotional rather than epistemic information (e.g., Stenberg & Hagekull, 2007; Schieler, Koenig, & Buttelmann, 2018; Striano, Vaish, & Benigno, 2006). While social referencing has been shown to index infants' response to the violation of expectation in cognitive and perceptual scenarios (Dunn & Bremner, 2016; Koenig & Echols, 2003; Walden, Kim, McCoy, & Karrass, 2007), here we demonstrate that infants are capable of strategically seeking pertinent epistemic information about the immediate environment from someone who can be regarded as knowledgeable about it. This finding is in line with the expertise rather than the comfort-seeking hypothesis of social referencing (Feinman, Roberts, Hsieh, Sawyer, & Swanson, 1992; Stenberg, 2009, 2013), but also extends it for the first time, to the best of our knowledge, specifically to referential ambiguity in word learning situations. Only a small number of recent studies investigated social referencing during epistemic uncertainty, and all did so with older children (Harris, Bartz, & Rowe, 2017, 16-33 months; Goupil et al., 2016, 20 months; Hembacher et al., 2017, 24 months; Vaish et al., 2011, 13 months). Unlike previous studies, our experimental manipulation placed infants in a more naturalistic situation where they had a mutually exclusive choice of who to look at - rather than whether or not to look at the social partners at all when facing high epistemic uncertainty (e.g., Kovács et al., 2014; Vaish et al., 2011), or doing so only after being experimentally trained rather than spontaneously (e.g., Goupil et al., 2016).

The current study shows that social referencing serves the function to actively seek relevant information when such information is actually needed. In spite of the Informant being knowledgeable throughout all experimental phases, infants preferentially looked at them only at test when asked a question they themselves could not answer, ruling out the possibility that the Informant was overall more engaging than the Non-Informant just because they were always providing specific and relevant information, including exclusively pointing to the object

as part of the information provision. Crucially, the same result emerged when directly comparing a subset of the familiarization trials with novel objects (last two familiarization trials) with an equal subset of the test trials with novel objects (first two test trials). Additionally, infants' hold-outs and gives as an early developing active communicative behavior (Boundy, Cameron-Faulkner, & Theakston, 2016) were not preferentially directed at the Informant at any stage (see Supplementary Materials), supporting our interpretation of interrogative selectivity of social looks at the opportunity to seek information episode only. These results suggest that infants generated social looks to the Informant not because they realized that they have specific and relevant information overall, but because they were the best source of such information when it was needed. This may also be explained by infants' general, rather than specific to situational knowledgeability, preference for seeking epistemic help from competent social partners (for a discussion see Mascaro & Sperber, 2009). Future studies should investigate whether infants pay attention to general competence cues as opposed to epistemic competence per se, as well as whether competence in one domain is generalized to other knowledge domains.

An alternative interpretation to our results, following a reinforcement learning process, could be that infants' looking was not driven by information seeking but

instead by anticipation of the correct response from the Informant. We believe this to be the less favorable explanation: infants' looks to the Informant did not increase as the trials progressed (in contrast to Kovács et al., 2014) and were selective to test trials only, but not familiarization, warm-up training, and reinforcement familiarization trials, some of which were interspersed with the test trials (Figure 1d, see Supplementary Materials for these results). Furthermore, our results suggest that social looks and duration of looks index different cognitive mechanisms at different phases of the procedure, such as attention to the adults as infants formed their respective epistemic profiles at familiarization, and intentional communication soliciting information-gathering at test. The meaning of infants' looks and looking time is generally debated (Aslin, 2007; Dunn & Bremner, 2016; Sim & Xu, 2019). These underlying differences may explain why our results were evident in the proportion of total looks, but not first looks, which were directed at the experimenter speaking first at each familiarization trial, or the length of visual fixations, which indexed encoding of experimenters' identity at familiarization, but underlined the lack of attention at the Non-Informant at test when seeking information selectively from the Informant.

We believe that the field is ripe for future investigations of information seeking through social referencing in preverbal infants. Our new paradigm would be easily applicable down to 6-month-old infants, and would enable a better understanding of how early this cognitive capacity emerges. Additionally, our paradigm could be improved by interleaving at test the trials with familiar objects (no uncertainty) with the trials with unfamiliar objects (epistemic uncertainty), further ruling out the possibility that infants look more at the knowledgeable informant because they anticipate the knowledge transmission to occur rather than actively soliciting it.

In sum, we have shown that infants reliably identify knowledgeable social partners and actively use social referencing to selectively seek information from them over others when required. Our results show that this capacity, at the heart of human cultural transmission, is available at least from 12 months of age. Infants know who to ask when information that is impossible to acquire otherwise, such as a label, is specifically relevant to them: they refer to a benevolent, knowledgeable and informative conspecific who can promptly satisfy their epistemic needs. Far from being passive recipients of top-down information from others' testimony, infants actively participate in the cultural interpersonal process of knowledge transmission, and they do so with all the basic communicative tools at their disposal.

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Figure 1:

Example of the stimuli (1a), experimental set up (1b), procedure (1c), and structure of the test trials (1d).

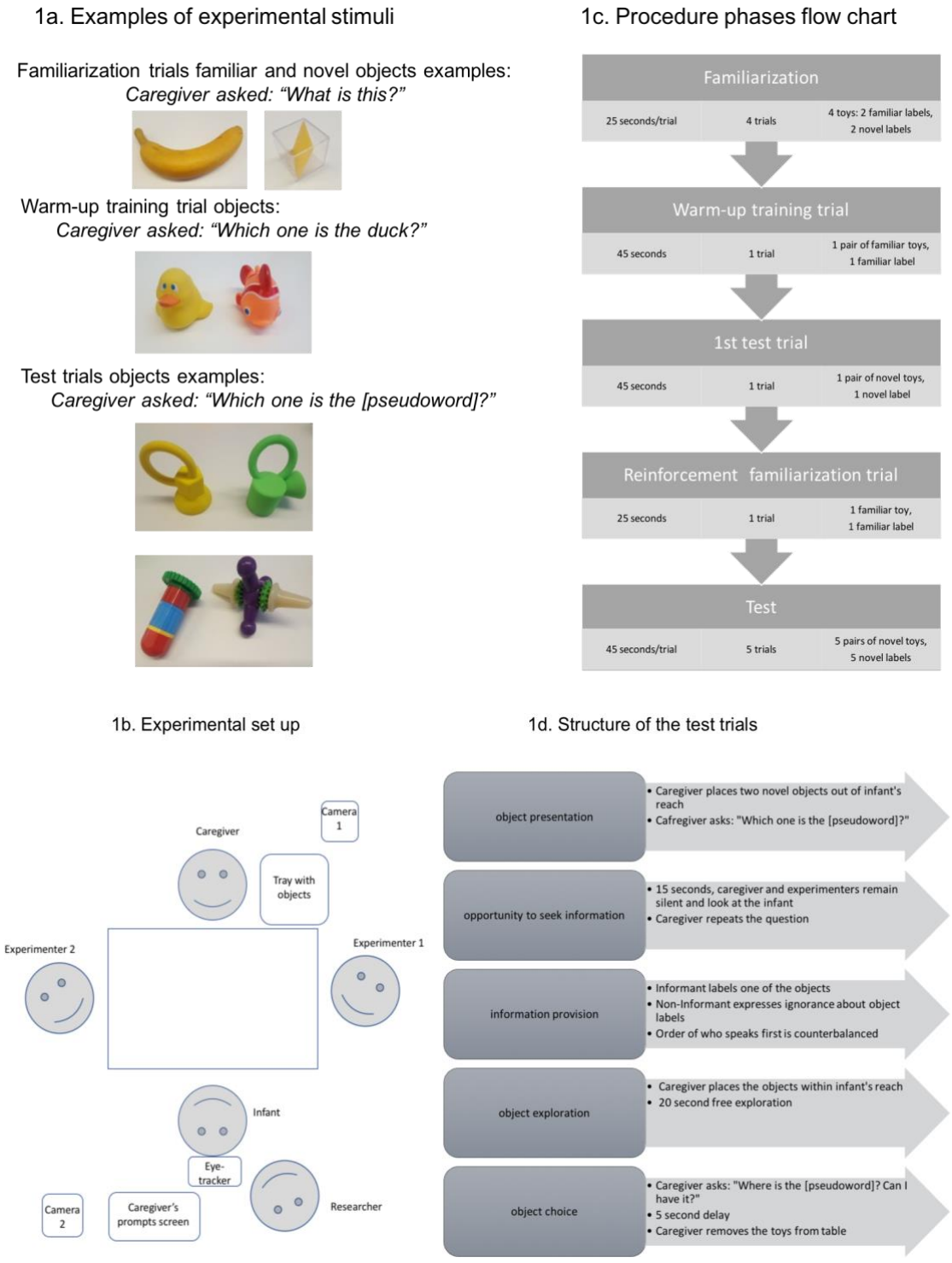
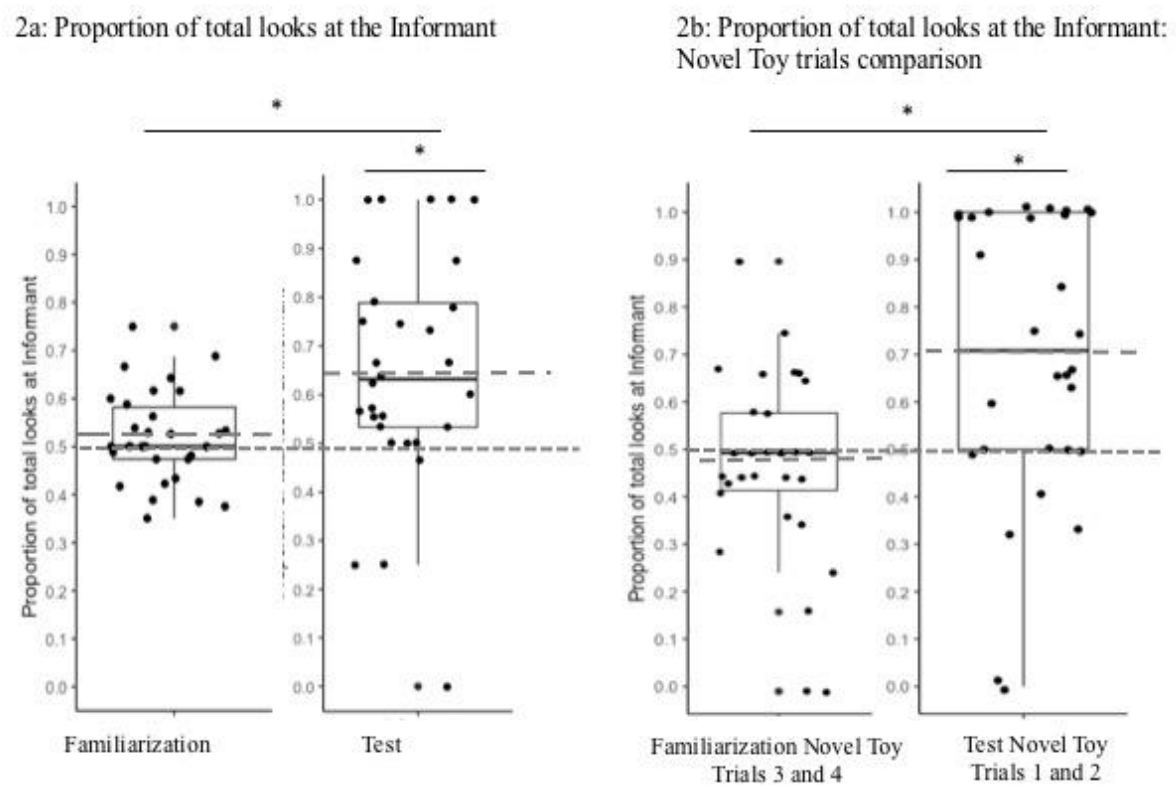


Figure 2:

Proportion of total looks at Informant (versus Non-Informant) at familiarization (2a) and test (2b) phases of the experiment. The dots represent the distribution of individual participants' proportion of total looks at the Informant during the Familiarization and Test phases (2a), and a subset of two novel toy trials during the Familiarization and Test phases (2b). Bold dashed lines represent the Mean values, chance level at .5 is represented by frequent dashed line; solid lines of the box plots show the median with the first and the third quartiles, the upper and lower whiskers represent scores outside the middle 50%.



* represent statistical significance at $p < .01$.

Supplementary materials

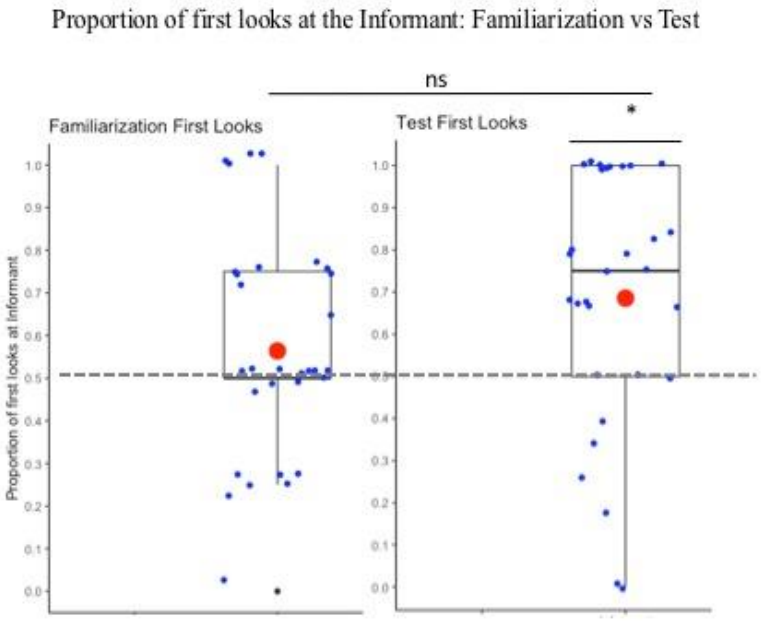
Table of contents:

Cross-phase comparison of first looks at familiarization and test

The proportion of infants' first looks at the Informant during the four familiarization phase trials did not differ significantly from the proportion of first looks during the six test trials, $t(29) = -1.69$, $p = .1$, $BF_{01} = 1.08$.

Figure S1:

Proportion of first looks at Informant (versus Non-Informant) at familiarization and test phases of the experiment. The dots represent the distribution of individual participants' proportions of first looks, dashed lines represent the chance level, red dot represents the Mean values, solid lines of the box plots show the median with the first and the third quartiles, the upper and lower whiskers represent scores outside the middle 50%. * represent statistical significance at $p < .01$.

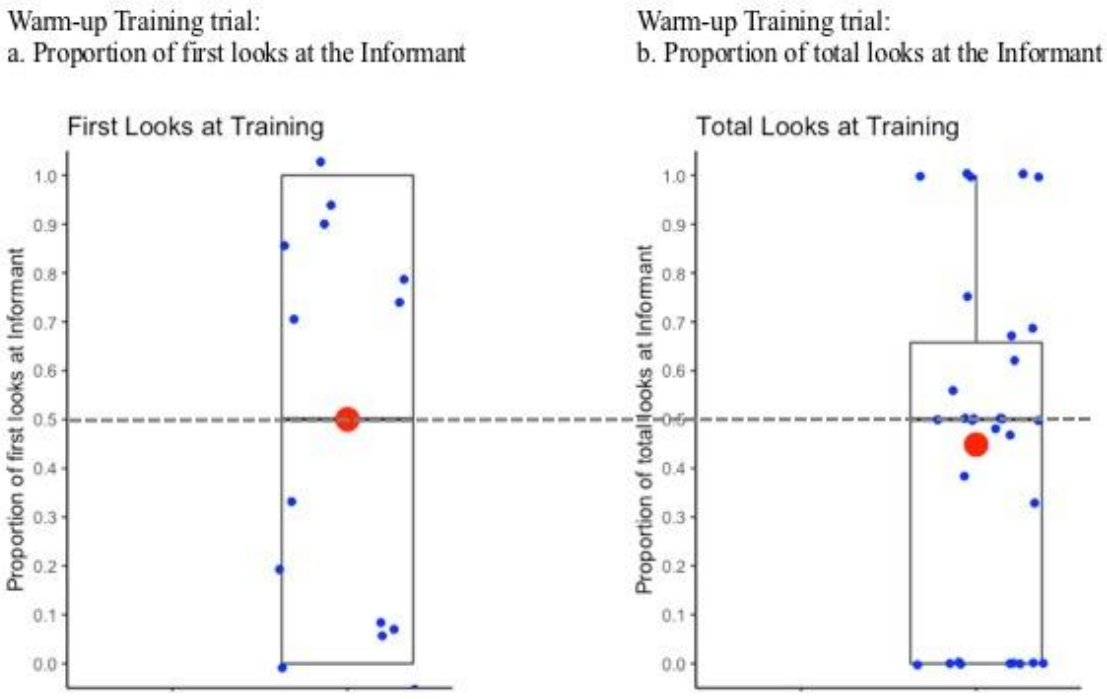


Warm-up training trial

The proportion of first looks directed at the Informant rather than the Non-Informant ($t(21) = 0$, $p = 1$, $BF_{01} = 4.48$) and the proportion of total looks ($t(21) = -.91$, $p = .37$; $BF_{01} = 4$) were both at chance.

Figure S2:

Proportion of first looks and total looks at Informant (versus Non-Informant) at the warm-up training trial of the experiment.

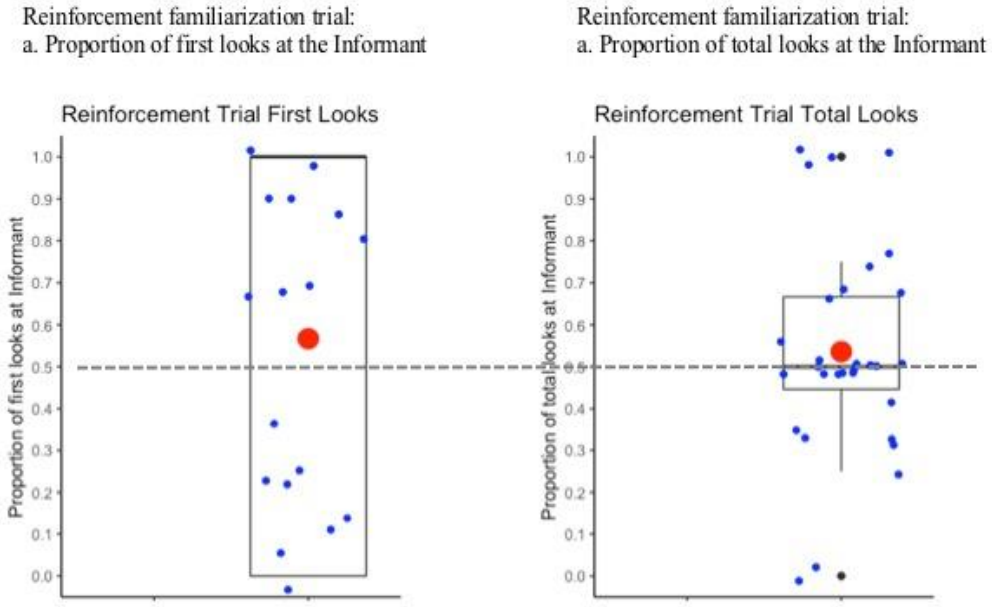


Reinforcement trial

The proportion of first looks directed at the Informant rather than the Non-Informant ($t(29) = .73$, $p = .23$, $BF_{01} = 3.1$) and the proportion of total looks ($t(29) = .77$, $p = .22$; $BF_{01} = 3$) were both at chance.

Figure S3:

Proportion of first looks and total looks at Informant (versus Non-Informant) at the reinforcement trial of the experiment.



Trial-by-trial analyses at test: first and total looks

We analyzed the trial-by-trial proportions of first and total looks generated to either the Informant or the Non-Informant at each of 6 test trials. Due to exclusion, 87% of infants completed trial 1, 83% finished trials 2 and 3, 77% progressed to trial 4, with substantially reduced percentage of valid trials 5 (57%) and 6 (53%). One-sample t-tests results are presented in Table 1.

Figure S4:

Distribution of the proportion of the first and total looks at the Informant across test trials. Large points indicate statistically significant one-sample t-test results at an alpha level of .5. Dashed lines represent the chance level.

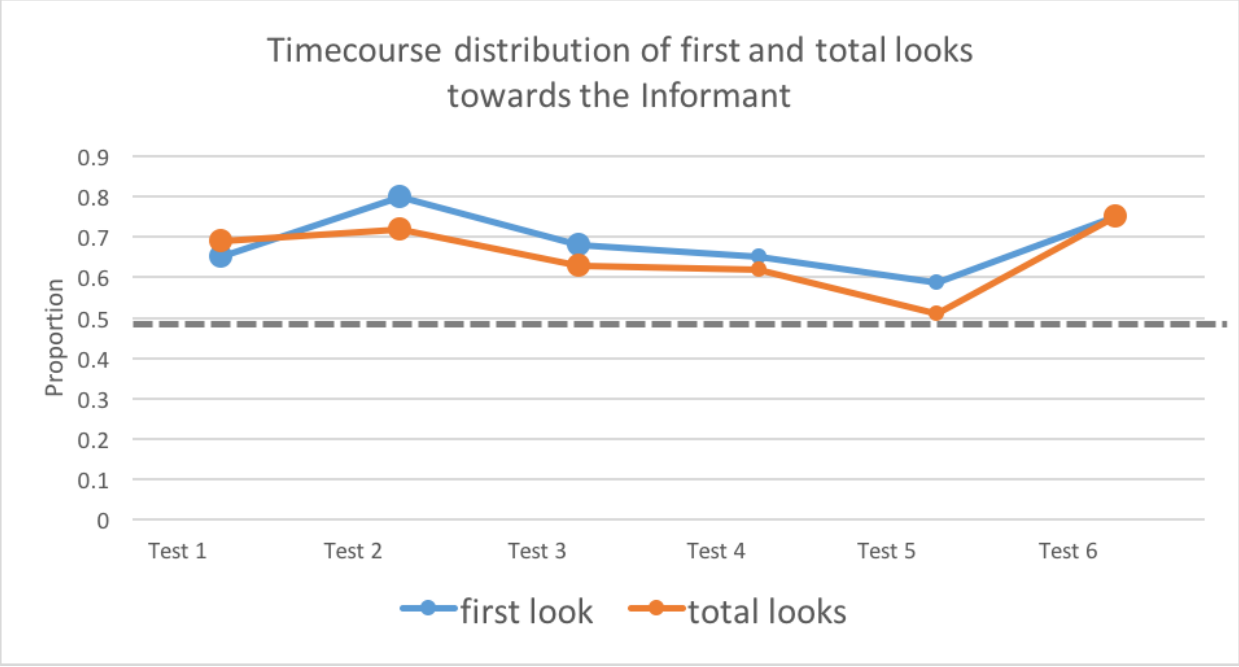


Table S1:

Results of the one-sample t-test analyses for each test trial

Trial/Looks	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
First Looks	$t(25) = 1.62$, $p = .05$	$t(24) = 3.7$, $p = .001$	$t(24) = 1.89$, $p = .04$	$t(22) = 1.5$, $p = .07$	$t(16) = 0.7$, $p = .24$	$t(15) = 2.24$, $p = .02$
Total Looks	$t(24) = 2.5$, $p = .01$	$t(24) = 2.97$, $p = .003$	$t(24) = 1.76$, $p = .05$	$t(22) = 1.5$, $p = .07$	$t(16) = 0.22$, $p = .41$	$t(15) = 3.73$, $p = .001$

Caregiver looks at experimenters

A relatively small subsample of trials contained unsolicited caregivers' looks at the experimenters: this occurred on 23% of total valid trials, specifically: with 43% of total familiarization trials, 10% of total warm up training trails, 30% of total reinforcement trials, and only 6% of total test trials.

We coded caregivers' first and total looks at the Informant and the Non-Informant throughout the phases of the procedure. At familiarization, we coded all looks that occurred during the whole 20-second trial; at test, we coded all looks during the 15-second silent period of opportunity to seek information.

At Familiarization, caregivers directed 59% of first looks (out of total 33 first looks made by caregivers) and 55% of total looks at the Informant (out of total 49 looks). At Test, caregivers directed 75% of first looks (out of total 6 first looks) and 43% of total looks at the Informant (out of total 7 looks).

One-sample t-tests revealed no significant looks preferences at the Informant over the Non-Informant at both Familiarization (first looks: $t(19) = .13$, $p = .45$; total looks: $t(19) = .13$, $p = .45$) and at Test (first looks: $t(4) = 1.5$, $p = .1$; total looks: $t(4) = .40$, $p = .35$).

To test whether caregivers' looks had an effect on infants' looks, we conducted a series of simple linear regression analyses, with the aim to delineate the effect of caregivers' first looks on infants' first looks at familiarization and at test and caregivers' total looks on infants' total looks at each phase.

The proportion of caregivers' first looks towards the Informant generated at familiarization was not predictive of infants' preferential first looks at the Informant at familiarization (β = -.18, $t(18)$ = - .89, p = .39) and at test (β = .12, $t(18)$ = .92, p = .37). The proportion of caregivers' first looks towards the Informant generated at test was not predictive of infants' preferential first looks at the Informant at test (β = -.29, $t(3)$ = -1.02, p = .39).

The proportion of caregivers' total looks towards the Informant generated at familiarization was not predictive of infants' preferential total looks at the Informant at familiarization (β = .07, $t(18)$ = .88, p = .4) and at test (β = .1, $t(18)$ = .86, p = .4). The proportion of caregivers' total looks towards the Informant generated at test was not predictive of infants' preferential total looks at the Informant at test (β = -.15, $t(3)$ = .92, p = .13).

Other communicative behaviors

A range of other non-verbal communicative behaviors were manually coded from the video data: pointing, reaching, vocalizing, and producing declarative and imperative communicative bids – all during the 15-second "opportunity to seek information" episode of the test phase.

We reasoned that pointing and reaching present a contrast corresponding to the contrast between declarative versus imperative motives (e.g., Southgate, Maanen, & Csibra, 2007). In our experimental setup, pointing towards the toys was operationalized

as a manifestation of declarative motives ("Look at this!"), while reaching was essentially imperative (i.e., "I want this; give it to me!"). Infants' vocalizations were operationalized as a proxy measure of frustration given the situational demands (i.e., not having access to the toy and lack of contingent communication from the adults).

Additionally, to further characterize these communicative behaviors, two separate unifying coding categories were created. Declarative bids were coded when at least one of the following conditions were met (adapted from Camaioni, Perucchini, Bellagamba, & Colonnesi, 2004): maintaining eye-contact with an adult whilst pointing at or reaching for the toys; generating eye-contact with an adult 2 seconds before pointing at or reaching for the toys or after pointing at or reaching for the toys; making eye-contact with an adult and smiling, babbling, waving or whimpering at them, but then becoming visibly upset when no response was received (i.e., when an attempt to engage an adult was unsuccessful); eye-contact with an adult while making gestures signifying uncertainty, such as tilting the head to one side, shaking the head 'no', shrugging shoulders, or making a hand flip gesture (e.g., Kim, Paulus, Sodian, Proust, 2016; Harris, Bartz, & Rowe, 2017). Imperative bids were instances of attempts to obtain the objects characterized by intent looking at the objects combined with reaching, pointing or vocalizing frustration at the same time, but not making simultaneous or occurring within 2 seconds eye-contact with adults. We also coded which adult such declarative and imperative communicative bids were directed at.

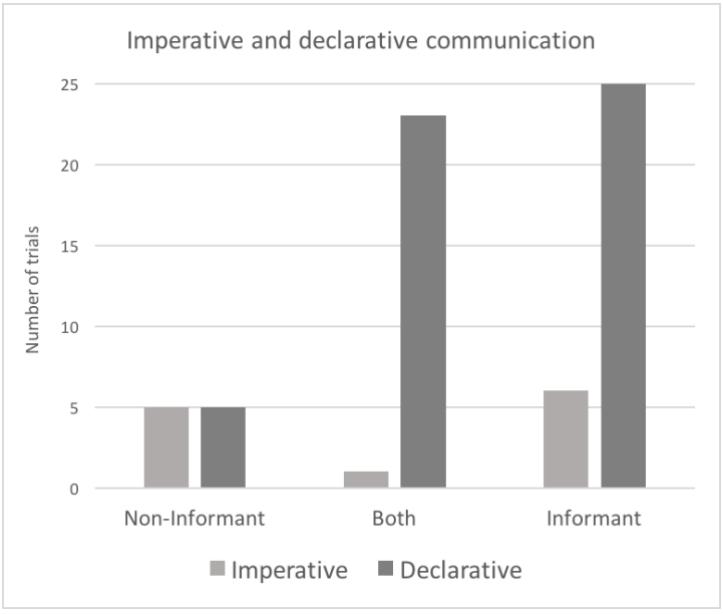
Six infants produced a pointing gesture which occurred on average in 9% of the test trials; 20 infants reached towards the objects in 56% of the trials; vocalizations from 22 infants accompanied 46% of the trials; declarative communication was evident in 48% of the trials generated by 21 infants, while imperative in 18% of the trials by 15 infants.

Declarative communicative attempts were significantly more frequent than the imperative communicative attempts ($t(28) = 2.37$, $p = .02$, paired-samples t-test) and the two were negatively correlated, $r = -.44$, $p = .02$. There was a moderate positive correlation of vocalizations with imperative communicative requests, $r = .46$, $p = .01$; and a negative correlation with pointing $r = -.40$, $p = .03$.

We further coded whether imperative and declarative communicative bids were directed at Informant, Non-Informant or at both at each trial. There were a total of 11 trials (9% generated by 9 infants) with imperative and 53 trials (41% by 21 infants) with declarative bids directed at the experimenters rather than the caregiver; see Figure S5. On average, across all infants the proportion of infants' imperative bids directed at the Informant was $M = .53$ ($SD = .51$) and of declarative bids $M = .72$ ($SD = .25$), however, no statistical analyses were performed on these data due to the limited number of infants featuring both types of communicative behaviors.

Figure S5:

The number of individual test trials with imperative and declarative communicative bids at the experimenters.



To evaluate whether these additional communicative behaviors had an effect on the primary outcome measures - first and total looks at test - we conducted exploratory regression analyses. We regressed the proportion of the first looks at test on pointing, reaching, vocalizations, imperative communication, and declarative communication, and the proportion of total looks on the same variables. In both models, none of the variables were statistically significant predictors (first looks: $F(5, 23) = .44$, $p = .82$; total looks: $F(5, 23) = .34$, $p = .89$).

Hold outs and gives

We coded whether infants were more prone to holding out an object or giving it to the Informant versus the Non-Informant, based on the previous work indexing these as active communicative behaviors (Boundy, Cameron-Faulkner, & Theakston, 2016). We analyzed these behaviors during the familiarization and test trials while infants had access to the toy (at test, during the object exploration episode, see Figure 1d). 17 infants generated hold-out and give behaviors during familiarization, and 10 did so during the test trials. One-sample t-tests revealed that infants had no preference for the Informant, neither at familiarization ($M = .51$; $t(16) = .09$, $p = .47$), nor at test ($M = .43$, $t(9) = -.57$, $p = .71$), and the paired-samples t-test showed no cross-phase differences ($t(6) = -.85$, $p = .43$). Further, we conducted exploratory regression analyses to evaluate whether hold outs and gives had an effect on our primary outcome measures: first and total looks at test. We regressed the proportion of the first looks at test on infants' average proportion of hold outs and gives at familiarization and test and the proportion of the total looks at test on the same variable, resulting in no statistically significant effects (first looks: $\beta = .15$, $t(17) = 1$, $p = .33$; total looks: $\beta = .04$, $t(17) = .29$, $p = .77$).

Object choice episode at test

Infants' choice of an object at test was coded following the caregivers' prompt ("Where is the [pseudoword], can I have it?") as initial preferential looking at, pointing at, reaching for or touching one of the objects in the pair. Averaged across test trials, responses from 21 children were coded as indicating a preference, but there was no evidence of a preference for the previously labeled object (M = .27, $t(29)$ = -5.73, p = 1, one-sample t-test).

Experimental Chapter 3: Active Information Transmission

Research presented in the previous chapter demonstrated that preverbal infants were keen to solicit knowledge from social partners who they regarded as possessing such knowledge, specifically when they could not obtain the needed information in any other way. They used one of the early available explicit communicative tools – social referencing – to initiate such information-gathering.

Together, studies 1 and 2 present novel evidence that infants take an active interrogative stance before developing a more sophisticated and complex information seeking tools, such as pointing and formulating questions verbally. These studies support the proposition that infants in their first year of life show sensitivity to epistemic uncertainty and knowledge distribution among social partners, exhibit epistemic vigilance in social contexts, and actively communicate with social partners to seek their epistemic input.

The social knowledge exchange process is inherently bi-directional and children are therefore active players at its both ends. While the body of literature on active social learning in early childhood is growing fast, less is known about children-initiated active information transmission. When do children teach others, who do they choose to share information with, and what kind of information do they tend to transmit? These are the overarching questions driving research into the developmental origins of child-led teaching.

Contributing to the nascent literature on early developmental precursors to information transmission, this chapter contains a study which investigated two-year-old

children's propensity to demonstrate novel toys' functions to an ignorant adult after learning them from other social partners. Specifically, in this study, we asked how different social and non-social cues which are present when children acquire new information affect the likelihood of its preferential transmission. We reasoned that if children's active learning can be affected by both the properties of information (e.g., object's functions) and the properties of the informant (e.g., being explicitly pedagogical), so might be their own active teaching. The present research therefore investigated the interaction of non-social (i.e., action complexity) and social (i.e., informant's pedagogical cues such as direct eye contact, child-directed speech, and explicit verbal teaching prompts) factors in shaping children's transmission choices.

Here, just as in a study presented in the previous chapter, toddlers were exposed to two competing sources of information – two interactive social partners, each demonstrating a separate piece of information: novel object's functions, which differed on the levels of action complexity and the mode of action demonstration (pedagogical and intentional but non-pedagogical). Upon encoding the epistemic value of information presented, toddlers were faced with a choice: which type of information to propagate further in the social knowledge exchange process. In this study, we demonstrated that toddlers were willing to actively teach a naïve adult what they knew, adding to the growing literature on of the factors affecting information transmission in early childhood.

This chapter contains the third paper in this journal format thesis, which examines the third research question: D*o toddlers preferentially transmit information that was taught in an explicitly pedagogical context or information that was easier to demonstrate but not taught pedagogically?*

This paper has been published in the same format as presented in this thesis:

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Two-year old children preferentially transmit simple actions

but not pedagogically demonstrated actions

Marina Bazhydai*

Priya Silverstein*

Eugenio Parise

Gert Westermann

*equal contributions

Contributions

MB, PS, GW and EP designed the study and wrote the manuscript. MB recruited and booked children for the experiment. MB and PS carried out the experiments. MB handled the data and coded the videos. MB performed all Frequentist analyses, and PS performed all Bayesian analyses.

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Conflict of interest statement

Authors declare no conflict of interest.

Data availability statement

The data that support the findings of this study are openly available in the Open Science Framework at https://osf.io/e2hvj/.

Keywords

- information transmission
- social learning
- pedagogical demonstrations
- action complexity

Research highlights

- We directly contrasted pedagogical demonstration with complexity of novel actions in a knowledge transmission paradigm with 2-year-old children.
- Children preferentially transmitted simple non-pedagogically demonstrated actions over pedagogically demonstrated complex actions.
- We found no evidence of preferential transmission of pedagogically demonstrated actions when both actions were matched for complexity.

Abstract

Children are sensitive to both social and non-social aspects of the learning environment. Among social cues, pedagogical communication has been shown to not only play a role in children's learning, but also in their own active transmission of knowledge. Vredenburgh, Kushnir and Casasola (2015) showed that 2-year-olds are more likely to demonstrate an action to a naive adult after learning it in a pedagogical than in a non-pedagogical context. This finding was interpreted as evidence that pedagogically transmitted information has a special status as culturally relevant. Here we test the limits of this claim by setting it in contrast with an explanation in which the relevance of information is the outcome of multiple interacting social (e.g., pedagogical demonstration) and non-social properties (e.g., action complexity). To test these competing hypotheses, we varied both pedagogical cues and action complexity in an information transmission paradigm with 2-year-old children. In Experiment 1, children preferentially transmitted simple non-pedagogically demonstrated actions over pedagogically demonstrated more complex actions. In Experiment 2, when both actions were matched for complexity, we found no evidence of preferential transmission of pedagogically demonstrated actions. We discuss possible reasons for the discrepancy between our results and previous literature showing an effect of pedagogical cues on cultural transmission, and conclude that our results are compatible with the view that pedagogical and other cues interact, but incompatible with the theory of a privileged role for pedagogical cues.

Introduction

Social transmission of information is achieved through observation, imitation, and explicit teaching. The human capacity to flexibly engage learners in pedagogical contexts is at the core of transmission of complex cumulative human culture (Burdett, Dean, & Ronfard, 2017; Caldwell, Renner, & Atkinson, 2017; Kline, 2015). Although socially-mediated learning in early childhood has been studied extensively, little is known about child-initiated teaching (Nakao & Andrews, 2014; Sobel & Letourneau, 2016; Ziv & Frye, 2004) and its cognitive mechanisms (Corriveau, Ronfard & Cui, 2017; Paulus, Kim & Sodian, 2015). Active transmission of information from children to others starts in infancy (Liszkowski, Carpenter, & Tomasello, 2008), but the majority of studies on child-initiated teaching focus on preschool to primary school age children (Flynn, Turner, & Giraldeau, 2016; Flynn & Whiten, 2012; Whiten & Flynn, 2010), leaving a gap in understanding the developmental trajectory of information transmission. This emerging body of research shows children's sensitivity to what and whom they are teaching (Gweon & Schulz, 2019; Kim, Kalish, Weisman, Johnson, & Shutts, 2016; Rhodes, Bonawitz, Shafto, Chen, & Caglar, 2015; Ronfard, Was, & Harris, 2016).

While research on information transmission in early childhood is limited, as they acquire knowledge, children are sensitive to both non-social and social aspects of the learning environment. Non-social factors include, among others, perceptual salience (Pruden, Hirsh-Pasek, Golinkoff, Hennon, 2006), novelty (Mather & Plunkett, 2012), perceived causality (Burdett et al., 2018; Ronfard, Was, & Harris, 2016), efficiency (Pinkham & Jaswal, 2011), and complexity or difficulty (Bannard, Rosner & Matthews, 2017; Flynn, Turner & Giraldeau, 2016; Kidd, Piantadosi & Aslin, 2012). Such salient factors guide integration of knowledge about objects, causal relations, statistical

patterns, and updating and rejecting of hypotheses in light of acquired evidence (Bonawitz, van Schijndel, Friel, & Schulz, 2012; Gopnik et al., 2017; Waismeyer & Meltzoff, 2017).

Social factors affecting learning include perceived intentions, competence, past accuracy, and social status of the informant or teacher (for reviews see Harris, 2012; Over & Carpenter, 2012; Tomasello, 1999). Furthermore, pedagogical cues, such as infant-directed speech (Eaves, Feldman, Griffiths, & Shafto, 2016), mutual gaze and joint attention (Striano, Chen, Cleveland, & Bradshaw, 2006), and explicit linguistic cues (Butler & Tomasello, 2016; Gelman, Ware, Manczak, & Graham, 2013), have been shown to selectively affect children's learning (Sage & Baldwin, 2011) in a way that is argued to not be able to be explained by heightened attention (but see Gredebäck, Astor, & Fawcett, 2018; Szufnarowska, Rohlfing, Fawcett, & Gredebäck, 2014).

Pedagogical cues have been shown to not only play a role in children's learning, but also in children's own active transmission of knowledge. Vredenburgh, Kushnir and Casasola (2015) showed that 2-year-olds were more likely to demonstrate an action to a naïve experimenter not present during the demonstrations after learning it in a pedagogical than in a non-pedagogical context. In their study, children were taught two possible actions on one toy. One action was shown in an explicitly pedagogical manner (involving infant-directed-speech and direct eye contact), whereas the other action was shown in an intentional but non-pedagogical way. Children were equally likely to learn both of these actions immediately following the demonstrations, but preferentially demonstrated the action that had been shown in a pedagogical context.

A variety of social learning theories propose that a human predisposition for learning from others, mediated by pedagogical cues, enables effective cultural transmission, thereby reducing the costs of unconstrained trial-and-error exploration.

These theories predict that knowledge is most likely to be effectively transmitted when it was learnt as a cultural convention (Csibra & Gergely, 2009; Harris, 2012; Tomasello, 1999, 2016; Vygotsky, 1978). For instance, Tomasello (2016) argues for pedagogical instruction being one of the pillars of cultural learning, with evidence accumulating that pedagogical contexts selectively enable children to generalize such information (e.g., Butler & Markman, 2012; Gelman et al., 2013).

While most pedagogical learning theories merely highlight the importance of pedagogical cues and are not specific about the relationship between these cues and other, non-pedagogical cues, the arguably most prominent such theory, Natural Pedagogy (NP, Gergely & Csibra, 2009; 2011), argues for a qualitative distinction between pedagogical and non-pedagogical cues. According to NP, humans have evolved to be sensitive to a circumscribed set of pedagogical cues (direct eye gaze, child directed speech, contingent reactivity), which directly create the expectation of communicative intention in the learner, circumventing the need to infer such an intention from other behaviors (Csibra, 2010). In this way pedagogical cues are thought to be a potent driver of infants' learning especially of culturally relevant knowledge that would be hard to acquire relying on observation alone, and their presence leads to the infant's effective encoding of such information. Nevertheless, as a privileged status for pedagogical cues in knowledge transmission is common to all described theories we refer to them here collectively as *Privileged Pedagogy (PP)* views.

An interpretation of pedagogical cues that is in contrast to views ascribing a qualitatively distinct role to them is that, through their salience, they merely enhance attention to the learning situation without assuming infants' understanding of communicative and referential intentions behind them (Heyes, 2016, 2017). In this way, pedagogical cues interact with other situational factors to affect the likelihood of

successful learning. In such a *Cue Combination* (*CC*) framework, each cue, weighted by its saliency, has an effect on the likelihood of some information being learned or transmitted, and combined weights of the cues favor learning of one piece of information over another. Such an approach resembles, for instance, the emergentist coalition model of word learning (Hirsh-Pasek, Golinkoff, & Hollich, 2000), which suggests that children attend to, weigh, and integrate a variety (coalition) of developmentally accessible cues (social, perceptual, cognitive, and purely linguistic) in learning new words. A combination of social and non-social cues has been shown to guide infants' attention, leading to effective learning outcomes in different settings (Barry, Graf Estes, & Rivera, 2015; Smith, Colunga, & Yoshida, 2010; Wu & Kirkham, 2010; Wu, Tummeltshammer, Gliga, & Kirkham, 2014). Extending this account beyond gradual weighted cue combination and presenting the social and non-social cue combination as a complex framework (Yurovsky & Frank, 2017), it has been proposed that domain general cognitive processes such as attention and speed of information processing explain developmental change in infants' use of social cues during word learning. Relately, rational constructivist approaches to social learning also argue for an integrative view, namely accounting for children's existing knowledge (Sobel & Kushnir, 2013) and statistical inference (Xu & Kushnir, 2013). Together, these approaches argue for embracing the complexity arising from real life learning situations, and for designing experiments which manipulate several competing cues while taking into account the different weightings of these cues.

Critically, while both *PP* and *CC* accounts assume a strong role for pedagogical cues in learning and transmission, they differ in how they explain the mechanisms underlying the effect of pedagogical cues. Whereas, for example, NP assumes that pedagogical cues have an evolved privileged and specific status in learning that is not

based on their salience (Csibra & Gergely, 2006, 2009, 2011; Senju & Csibra, 2008; Yoon, Johnson & Csibra, 2008), others have argued that indeed the role of pedagogical cues is salience-based and have shown that non-pedagogical salient cues may lead to the same effects (Gredebäck, et al., 2018; Szufnarowska et al., 2014). Other work found that previous evidence for a privileged status of pedagogical cues may be difficult to replicate (Silverstein, Gliga, Westermann, & Parise, 2019), and that both independently accumulated statistical evidence and an explicit pedagogical stance that highlights the importance of information affect the likelihood of successful learning (Buchsbaum, Gopnik, Griffiths, & Shafto, 2011).

Studies that are aimed at specifically evaluating the function of pedagogical cues typically contrast a pedagogical and a non-pedagogical condition with other cues held constant (e.g., Senju & Csibra, 2008; Vredenburgh et al., 2015), and can therefore be accounted for both within the *PP* and *CC* frameworks. In order to disentangle these two accounts, it is necessary to manipulate both pedagogical and non-pedagogical aspects of the learning situation, but few studies have taken this approach. Previous findings from studies pitting pedagogical against other cues have focused on the efficiency of an action for achieving a specific goal, and have been inconclusive: different studies found selective preference for pedagogical cues (Marno & Csibra, 2015), equal rates of imitation of pedagogically cued and efficient actions (Brugger, Lariviere, Mumme, & Bushnell, 2007), imitation of inefficient actions only after pedagogical demonstration but not after independent exploration (Pinkham & Jaswal, 2011), or effects of pedagogical cues in overriding children's propensity to over-imitate inefficient actions (Hoehl, Zettersten, Schleihauf, Grätz, & Pauen, 2014).

Building on Vredenburgh et al.'s (2015) finding that 2-year-olds are more likely to demonstrate an action to an adult after learning it in a pedagogical rather than non-

pedagogical context, in the present study we set to investigate which of two potentially competing cues - action complexity as a non-social cue and pedagogical demonstration as a social cue - selectively affects the likelihood of an action being shown to an ignorant adult. Although Vredenburgh et al. interpreted their results within a *PP* framework, we here aimed to directly evaluate *PP* vs. *CC* accounts by pitting an experimenter's pedagogically demonstrated complex action against another's non-pedagogically demonstrated simple action and observing which action was then preferentially transmitted by the child to a third, naïve experimenter. We focused on 2-year-old children to enable direct comparison between our results and those found by Vredenburgh at al.

While largely adopting Vredenburgh at al.'s (2015) experimental paradigm, we made several crucial changes to the procedure and some of the phrasing to provide a more stringent test of the pedagogical manipulation, by stressing the experimenter's direct, explicit teaching intention. Specifically, we changed the verbal prompt used by the experimenter performing the pedagogical demonstration from "Look! Do you see this?" to "Look at this! This is how you do it!", and the prompt used in the non-pedagogical demonstration from "I like this! Nice!" to the accidental discovery prompt: "What's this? Oh, that's how you do it". Both phrases could (and should) lead to social learning, but the difference lies in demonstrators taking the intentional and norm inducing pedagogical as opposed to intentional but non-directive non-pedagogical stances. We ensured that both demonstrators did not interact with children prior to the experiment to control for potential preferences for one over the other, while the third experimenter acting as an ignorant person, on the contrary, was familiar to them and strongly evoked the conventional, normative context by expecting action transmission from children (saying "Can you show me how to play with it?", which is a change from

"What does this do? Can you show me?"). Collectively, these modifications were made to provide a more controlled manipulation and a more specific test of the effect of pedagogy above and beyond normativity inferences made by children from observing demonstrations (e.g., Casler, Terziyan, & Greene, 2009; Schmidt, Butler, Heinz, & Tomasello, 2016), while maintaining interactive engagement in the aim of ecological validity.

For the non-social cue, we manipulated action complexity, or difficulty of execution. Simple actions are faster to perform, require less effort, and have a higher probability of achieving the desirable outcome, and thereby, if we assume *CC*, action simplicity may outweigh the enhanced attention to more complex actions afforded by pedagogical cues. This reasoning is also in line with recent findings that older children transmit information to others in accordance with principle of the utility calculus, making rational and efficient decisions based on the complexity of information and the perceived needs of the naive learner (Bridgers, Jara-Ettinger, & Gweon, 2019; Gweon & Schulz, 2019). Note that this approach is in contrast to studies manipulating the efficiency cue, where different manners of executing an action result in the same outcome (Marno & Csibra, 2015; Pinkham & Jaswal, 2011). We chose to instead manipulate complexity in order to ensure there were qualitatively different 'pieces' of information (i.e. actions with different outcomes) to learn and transmit.

In Experiment 1, we directly contrasted *PP* and *CC* explanations for children's choice of action transmission by manipulating pedagogical cues and action complexity simultaneously. *PP* would argue that pedagogically transmitted actions should be transmitted preferentially as pedagogical cues hold a privileged status over other cues (Csibra, 2010; Csibra & Gergely, 2006). In contrast, from a *CC* perspective, pedagogical cues and action complexity should interact to lead to children's preferred

choice of action based on the relative weighting of the cues, so that pedagogical cues can be outweighed by information complexity. Then, in order to clarify the results of Experiment 1, in Experiment 2 we conducted a replication of Vredenburgh et al.'s (2015) manipulation of pedagogical cues while matching action complexity, retaining other methodological changes outlined in Experiment 1. Data, example videos, and supplementary results can be found on the Open Science Framework (OSF; https://osf.io/e2hvj/).

Experiment 1 method

Participants

Thirty-one 24-month-old children from a local community in a small city in Northwestern England participated in the experiment (15 females, M_{age} = 24 months 2 days, *SD* = .49, range 23.28-25.25 months). Two more children were tested but not included in the final sample due to failure to perform any actions.

Stimuli

Two unfamiliar toys served as stimuli in two trials (see Figure 1a). Each toy had two target functions, each producing a unique attractive sound. The first toy included two different buttons. One of the buttons was visibly located on the surface of the toy and could be pressed with a finger (simple action). The second button was hidden inside the toy but could be pressed with a hammer-like tool slotted into the toy (complex action). The second toy included a spiral feature, which made a sound when squished down (simple action), and a shaker feature that needed to be removed from the object before shaking to produce the sound (complex action). Toys were designed specifically so that the actions were not obvious, with many distracting non-functional elements. All action outcomes produced comparable sounds that differed in the complexity required to elicit them.

Procedure

The experiment was divided into two phases: a Demonstration (including a Pedagogical and a Non-pedagogical demonstration and a post-demonstration) and a Transmission phase. Experimenter 1 (E1) briefly interacted with the child during a warm up before the Demonstration started. The child was seated in a high chair at a rectangular table, with the caregiver sitting slightly behind and to the side of the child (see Figure 1b). The caregiver was instructed not to interfere in any way. Following the warm up phase, E1 told the child that she would now leave the room and that her friends would like to come in with a new toy that she herself had never seen. She then left the room and closed the door. There were two consecutive trials, one for each toy. Each trial included all phases. The entire procedure was filmed using two video cameras.

Demonstration phase. Experimenters 2 and 3 (E2 and E3), previously unseen by the child, were assigned to either the pedagogical or non-pedagogical demonstration, with order and condition counterbalanced across trials and participants. Upon E1 leaving the room, E2 and E3 entered, bringing in the first toy. They sat side by side across the table, facing the child. E2 and E3 each demonstrated one action on the toy three times, either pedagogically (always the complex action) or non-pedagogically (always the simple action). Then (Post-demonstration*)* the experimenter who had just performed the action placed the toy in front of the child and asked: "Can you do it?" If the child performed the demonstrated action within 15 seconds, the phase was finished, the toy returned to the other end of the table, the other experimenter demonstrated the other action and asked the child to perform it. If the child did not act after 15 seconds, the experimenter asked: "Can you show me?". Throughout the demonstration, the other experimenter gazed downwards. Upon completing the demonstrations, both experimenters left the table and sat in the far corner of the room behind the child.

Pedagogical demonstration. The experimenter made frequent eye contact with the child throughout the demonstration and spoke in child-directed speech. After taking a look at the toy, the demonstrator looked at the child, establishing joint attention, and said excitedly: "Look at this! This is how you do it!". She then demonstrated the complex function in a slow, deliberate manner, repeating it 3 times, alternating her gaze between the child and the object.

Non-pedagogical demonstration. The experimenter maintained attention on the toy, making no eye contact with the child. She looked at the toy and uttered in a self-addressed manner in an adult-directed speech: "What's this? Oh, that's how you do it". The demonstrator performed the simple function in a slow, deliberate manner and repeated it 3 times.

Transmission phase. E1 knocked at the door and re-entered the testing room, greeted the child and showed excitement upon noticing the toy on the table, saying: "Wow! Is that your new toy? That's an interesting toy! I've never seen that before! Can you show me how to play with it?" If the child did not perform any actions after 15 seconds, the experimenter asked: "Can you show me what this toy does?" After 30 seconds, the experimenter thanked the child and took the toy away, leaving the testing room.

Coding

In order to be included in the final sample, children had to contribute at least one of the two experimental trials. Twenty-five children contributed both trials, and 6 children contributed one.

Trial exclusion. Six individual trials were excluded from final analyses due to children's failure to perform any actions (N = 4), experimenter error (N = 1), and parental interference (N = 1).

Post-demonstration. For each of the four post-demonstrations (two actions by two objects), we coded whether children performed the target action (hereafter called 'manipulation check') and whether this resulted in achieving the outcome, i.e. sound ('achieving the action outcome'). Note, we have used the terminology "performed" for actions that were attempted by the children regardless of whether they achieved the desired outcome, in contrast to "achieving the action outcome". We created an additional dichotomous variable ('exploratory behaviors'): accidentally discovering the non-target action during the first action's post-demonstration.

Transmission phase. The exact sequence of actions performed in each transmission phase (one per toy/trial) was coded, resulting in two measures: which action was shown first to the experimenter ('first action') and number of switches to each action type ('number of actions').

Inter-rater reliability. An independent blind coder performed the offline coding. Another researcher double-coded 20% of the data. We used Cronbach's α (for continuous variables) and Cohen's κ (for dichotomous variables) to assess coders' agreement, who were found to be highly reliable, $\alpha = .89$ and $\kappa = .84$. All disagreements were resolved in a joint discussion. Where the two coders differed in their coding of continuous variables by over 50%, the video was jointly recoded and a final code produced. When the two coders' responses differed by less than 50%, an average was used.

Experiment 1 results

Statistical tests used were consistent with those by Vredenburgh et al. (2015).

Post-demonstration

Trial order (and toy) did not have an effect on manipulation check (Pearson's $chi^2 = 2.8$, $p = .09$) and on achieving the outcome of the action ($chi^2 = .85$, $p = .36$), we therefore combined across these factors for further analyses.

Manipulation check. Children passed the manipulation check on 86% of trials (i.e. performed the action after demonstration), and this did not differ between simple non-pedagogically taught actions and pedagogically taught complex actions (McNemar's $p = .69$).

Achieving the action outcome. Children achieved the action outcome on 57% of trials, and were significantly more likely to achieve the outcome of simple action (this happened in 98% of the trials) than complex action (only 15% of trials), Pearson's $chi^2 = 46.56$, $p < .001$, despite successfully passing the manipulation check in both types of actions.

Exploratory behaviors. In 48% of post-demonstration trials, children accidentally discovered the non-target action, both simple (N = 31) and complex (N = 22), Pearson's $chi^2 = 3.9$, $p = .05$.

Transmission

To test which action the children preferentially selected during this phase we examined two main variables: the choice of the first action and the number of actions.

First action. First actions from both trials were converted into scores: +1 (only demonstrated complex action first), 0 (one demonstration of each action first), and -1 (only demonstrated simple action first). These scores were compared to chance (0). Children performed the simple non-pedagogically demonstrated action first significantly more than they performed the complex pedagogically demonstrated action first ($t(30) = 2.68$, $p = .01$, 95% CI [-.68, -.09], Cohen's $d = .49$, one sample t-test), see Figure 2a.

Number of actions. The majority of children (79%) performed both actions in both trials. Children performed a higher number of simple (M = 1.61, SD = .84) than complex (M = 1.23, SD = .5) actions, $t(30) = -2.47$, p = .02, 95% CI [-.71, -.07], Cohen's d = .55, paired t-test, see Figure 3.

Exploratory behavior analyses. The choice of the action transmitted first was not affected by accidental discovery of the non-target action not shown in the demonstration phase (trial 1: Pearson's chi^2 = 1.81, p = .18; trial 2: Pearson's chi^2 = 1.54, p = .21), nor by whether the child performed both actions at the transmission phase (trial 1: Pearson's chi^2 = .05, p = .82; trial 2: Pearson's chi^2 = 1.17, p = .28).

Experiment 1 discussion

We found support for children's preferential transmission of the simple non-pedagogically demonstrated actions over the pedagogically demonstrated complex actions with two converging measures. Children transmitted the simple non-pedagogically demonstrated action first more often, and they performed more of these actions. Our complexity manipulation was successful, in that children found it difficult to achieve the outcome of the complex actions, which is considered a good manipulation of complexity in other studies of information transmission (e.g., Whiten & Flynn, 2010). This does, however, make it possible that the actions were so complex that children did not preferentially transmit them due to developmental motor skill deficiencies; it has been previously found that toddlers will not imitate an action that they cannot motorically achieve (Paulus, Hinnius, Vissers, & Bekkering, 2011, but see Nielsen, 2006). Crucially, however, in our study, overwhelmingly children transmitted both actions despite preferentially (i.e., first) transmitting the simple action. Likewise, there was no relationship between infants' achieving the action at post-demonstration and later transmitting it: children's preferential transmission of the complex action was not

predicted by their successfully achieving the outcome: of the 16 children who transmitted the complex action first, 4 had achieved its outcome at post-demonstration but 12 had not.

These results (in combination with those by Vredenburgh et al., 2015) are best understood within a *CC* account. When pedagogical cues were manipulated alone, actions demonstrated pedagogically rather than non-pedagogically 'won' (Vredenburgh et al., 2015). However, as shown here, when pedagogically demonstrated complex actions were pitted against non-pedagogically demonstrated simple actions, simple actions 'won', suggesting that enhanced salience resulting from pedagogical cues is weighted against action simplicity in children's choice of which action to transmit preferentially. This is not to say that it is impossible that even under a CC framework, pedagogical cues could not outweigh simplicity.

However, with our design we could not tell whether our results showed that the properties of the simple action *overrode* the effect of pedagogical demonstration, or instead whether we, in contrast to Vredenburgh et al. (2015), might find that in our set-up pedagogical teaching does *not* lead to preferential transmission in the first place. To this end, we decided to conduct a replication of the study by Vredenburgh et al. (2015). We used the same procedure as in Experiment 1, except that action complexity was now matched for both pedagogically and non-pedagogically demonstrated actions in each trial. We thus had one trial with two simple actions (as in Vredenburgh et al., 2015) and the second trial with two complex actions, allowing us to compare how children perform on both pairs at the transmission phase (note that the trial with the simple actions always occurred first in order to ease children into the procedure).

Experiment 2 method

Participants

Thirty-one 24-month-old children participated in this experiment (14 females, M_{age} = 24 months 4 days, *SD* = 0.36, range 23.28-24.69 months). Three more children were tested but not included in the final sample due to failure to perform any action at post-demonstration or transmission phases (N = 1) and parental interference (N = 2).

Stimuli

Stimuli were the modified toys from the Experiment 1, where the two functions of each toy were now matched for complexity, with the toy used in the first trial always operated with two simple actions, and the second toy (second trial) operated with a pair of complex actions (see Figure 1a).

Procedure and coding

The procedure was identical to Experiment 1, bar the difference in manipulation (i.e. now actions were matched for complexity rather than contrasted by complexity in each trial). We intentionally did not counterbalance the order of the simple and complex trials so that children would be eased into the procedure with the simple trial. For this reason, we did not compare simple and complex trials statistically, as this manipulation was confounded with trial order. Twenty-two children contributed both trials, and 9 children contributed one of the trials.

Trial exclusions. Nine individual trials were excluded from final analyses due to failure to perform any actions (N = 5) and experimenter error (N = 4).

Coding. The experimental procedure and coding were identical to Experiment 1, except for the addition of action duration as an outcome measure previously shown to be sensitive to this manipulation (Vredenburgh et al., 2015). Thus, the duration of actions performed by the children was manually coded offline frame by frame, from the first frame of the child touching the functional part of the toy. This measure was not

reported in Experiment 1 due to the inherent difference in time needed to complete complex and simple actions (these results can be found in Supplementary Materials).

Inter-rater reliability. The coders achieved high reliability, with continuous variables producing Cronbach's $\alpha = .87$ and dichotomous variables resulting in Cohen's $\kappa = .90$.

Experiment 2 results

Post-demonstration

Manipulation check. Children passed the manipulation check on 97% of trials, and the pass rate did not differ between the two actions (McNemar's $p = .69$; trial 1/simple: 93% of children passed the manipulation check; trial 2/complex: 86% of children).

Achieving the action outcome. Children were equally able to achieve the outcome of the pedagogically and the non-pedagogically demonstrated actions (McNemar's $p = 1$; trial 1/simple: 96% of children achieved the simple actions outcomes; trial 2/complex: 31% achieved the complex action outcomes).

Duration. There were no significant differences in how long children spent executing the target actions in both conditions *(*$t(51) = .33$, $p = .74$, paired t-test).

Exploratory behaviors. In 40% of post-demonstration trials, children accidentally discovered the non-target action, but this did not differ between pedagogically demonstrated actions and non-pedagogically demonstrated actions in terms of both prevalence (McNemar's $p = .52$), and duration of time spent on these actions ($t(50) = .78$, $p = .44$, paired t-test).

Transmission

First action. Children did not perform the pedagogically demonstrated action first significantly more than the non-pedagogically demonstrated action ($t(30) = .00$, p

= 1.0, one-sample t-test; Figure 2b) or separately for either trial (trial 1/simple: $t(30) = .00$, $p = 1.0$; trial 2/complex: $t(30) = .00$, $p = 1.0$). No statistical inference can be derived from this non-significant result (Lakens, McLatchie, Isager, Scheel & Dienes, 2018). Collapsed across trials, a default Bayes factor (Rouder, Morey, Speckman, & Province, 2012) with a wide Cauchy distribution (scale of effect = 0.707) yielded BF01 = 3.86. We can conclude that the data constitute moderate evidence for the null hypothesis (Jeffreys, 1961).

Number of actions. The majority of children (81%) performed both actions in both trials. The number of pedagogically and non-pedagogically demonstrated actions did not significantly differ overall ($t(30) = .40$, $p = .69$, paired t-test), or separately for either trial (trial 1/simple: $t(27) = -.25$, $p = .80$; trial 2/complex: $t(27) = .24$, $p = .81$), see Figure 3. Collapsed across trials, a default Bayes factor with a wide Cauchy distribution (scale of effect = 0.707) yielded BF01 = 3.69, establishing moderate evidence for the null hypothesis. Overall, children performed more actions during trial 1 (simple) than during trial 2 (complex): $t(21) = 3.91$, $p < .001$; 95% CI (.81, 2.65).

Duration of actions. Children did not spend significantly longer performing either of the actions overall ($t(30) = .19$, $p = .85$, paired t-test), or separately for either trial (trial 1/simple: $t(27) = -.50$, $p = .62$; trial 2/complex: $t(24) = .22$, $p = .83$). Collapsed across trials, a default Bayes factor with a wide Cauchy distribution (scale of effect = 0.707) yielded moderate support for the null hypothesis, BF01 = 3.79.

Exploratory behavior analyses. Whether or not a child accidentally discovered the action that was not shown to them in the demonstration phase (trial 1: Pearson's $chi^2 = 0.70$, $p = .40$; trial 2: Pearson's $chi^2 = 0.71$, $p = .79$), and whether or not a child performed both actions at the transmission phase did not affect which action they chose

to transmit first (trial 1: Pearson's $chi_2 = 0.00$, $p = 1.00$; trial 2: Pearson's $chi_2 = .52$, $p = .47$).

Experiment 2 discussion

Contrary to the results by Vredenburgh et al. (2015), we found no evidence of preferential transmission of pedagogically demonstrated actions even when both actions were matched for complexity, indexed through first action, duration of actions, or number of actions. This overall result was also found separately for trials with two matched simple actions and two complex actions. This finding is supported by Bayes Factor Analysis, which shows moderate support for the null hypothesis.

Critically, even in the second trial, where both actions were complex, children still transmitted both actions, despite the outcomes only being achieved by 31% of children at post-demonstration and 40% of children at transmission phase. Importantly, ignoring all possible effects of our complexity manipulation, even in the simple trial (which is comparable to the actions used in Vredenburgh et al.), we saw no preferential transmission of the pedagogically demonstrated action.

There are several possibilities for why we did not replicate Vredenburgh et al.'s (2015) finding. First, it is possible that our finding is a Type 2 error. However, this is unlikely given Bayes Factor Analysis showing moderate support for the null hypothesis across the range of measures used, and very similar results across the simple and complex action trials. We stress that the changes to the pedagogy manipulation that we made in our design, as compared to Vredenburgh et al., aimed for an even stronger and more stringent comparison of pedagogical versus non-pedagogical demonstration, making us more likely to detect the differences between the manipulations. It is also possible that the original finding was a Type 1 error. As no other studies to date have replicated this finding, this remains a possibility. Future research could investigate the

subtleties required for reproducing this effect, and whether the underlying theory should be modified accordingly to include these specific constraints.

Another possibility is that there are key differences between Vredenburgh et al.'s (2015) and our experiment. For example, it is possible that our verbal prompts in effect meant that both conditions were considered normative by the children, in that both prompts contained "this/that is how you do it". In our attempt to create a more controlled manipulation of pedagogical cues, whereby the only difference between prompts was the pedagogical nature, we may have inadvertently created a more normative context for both conditions. Nevertheless, normativity is not the defining feature of pedagogical context, and in *PP* a pedagogical transmission of normative information would still be preferred over non-pedagogical transmission of equally normative information (Csibra & Gergely, 2009; Csibra, 2010). The defining features of pedagogical context (which we did manipulate) are the presence of ostensive cues and explicit teaching. Future research can disentangle the effect of pedagogical context and normativity in information transmission.

Within the proposed *CC* framework, it is also possible that differences in the specific pedagogical cues and specific actions used in the two studies alter the specific weighting of cues. In our Experiment 2, the inherent interest of the actions may have outweighed the salience difference introduced by manipulating pedagogical cues, whereas in the study by Vredenburgh et al.' this was not the case. An analogy to illustrate this possibility is a child receiving two presents for their birthday, one accompanied by 'pedagogical' cues ('Wow, look at this, a present for you!'), and the other just placed in front of the child. The child might be so excited about the presents per se that the manner (social context) in which they were delivered makes no discernible difference to their interest in them.

Finally, it is possible that, in contrast to Vredenburgh et al.'s (2015) finding, pedagogical cues do not modulate preferential transmission of actions. In light of strong evidence that explicit pedagogical cues are of special importance to children in a variety of learning situations (Butler & Markman, 2012, 2014, 2016; Csibra & Gergely, 2009; Marno & Csibra, 2015) this would be surprising. Nevertheless, Vredenburgh et al's study was the first to extend the notion of the importance of pedagogical cues from learning to a child's active transmission of information, and it is possible that factors that are important in learning do not necessarily translate to information transmission, or do so at a later age than currently investigated. Future research should therefore focus on examining the contexts under which different cues combine to affect transmission.

General discussion

In this study we investigated how two types of cues (pedagogical demonstration and action complexity) affect children's transmission of recently demonstrated actions to a naïve adult, testing the prediction of a Privileged Pedagogy (*PP*) account that pedagogical cues would ensure preferential encoding of the action even despite its higher complexity, against a Cue Combination (*CC*) view that both pedagogical and complexity cues would be weighted to determine which action was preferentially transmitted. We report evidence that children preferentially transmitted simple non-pedagogically taught actions over pedagogically taught complex actions (Experiment 1), and no evidence of preferential transmission of pedagogically demonstrated actions when both actions were matched for complexity (Experiment 2), with moderate support for the hypothesis that pedagogical cues have no effect on preferential transmission.

Our results are compatible with the *CC* view, and incompatible with the *PP* view. The *CC* framework can explain this pattern of results, and the difference of our results compared to those of Vredenburgh et al. (2015), if as well as the cues that we

purposefully manipulated (action complexity and pedagogical demonstration) we also take into account the intrinsic properties of the toy. It is possible that compared to Vredenburgh et al. (2015), the inherent salience of our toys and our actions was higher. In this way, even if pedagogical demonstration did have some weighting, this did not incur a big enough difference to affect children's preference for action transmission. This is in contrast to Experiment 1, where there are intrinsic action properties that enhance the likelihood of transmission of the simple action. However, we note that although our results are *compatible* with the *CC* view in this way, future research should quantify and examine in more detail the relative weightings of different cues in determining outcomes for learning and transmission.

Several features of our study and that by Vredenburgh and colleagues warrant discussion and further research. First, it is possible that children were not sensitive to the pedagogy manipulation and instead considered the whole demonstration phase as a uniform learning episode, where one demonstrator is ostensibly more communicative than the other. Although we manipulated pedagogy explicitly, using various established cues, a more extreme manipulation of pedagogical and non-pedagogical cues may help resolve this consideration (e.g., Marno & Csibra, 2015). However, this may be at the expense of ecological validity, and would add further confounds that could be responsible for any differences found (as opposed to the presence of pedagogical cues themselves).

As we chose to manipulate the complexity of the actions by varying their ease and transparency of execution, this resulted in the complex actions being harder to achieve for some of the participants. Although this raises the possibility that it discouraged some children from choosing to transmit complex actions regardless of the manner in which they were demonstrated, three main points speak against this

interpretation. In Experiment 1, in trials where children transmitted the complex action preferentially (16), they were no more likely to have been able to achieve the outcome at post-demonstration than not (4 achieved, 12 did not). In Experiment 2, the results for the trial in which both actions were complex showed that even with low achievability, infants still transmitted both actions. In the trial where both actions were simple (comparable to Vredenburgh et al., 2015), children showed the same pattern: there was no difference in their transmission of pedagogically and non-pedagogically demonstrated actions. Hence, there is no evidence that being unable to achieve the outcome of the complex action affected children's transmission choice. Future research should investigate the relationship between the ability to achieve the outcome of an action and its transmission, with a large enough sample to statistically examine these individual differences.

Another promising avenue for future research is cultural transmission of different types of information (Corriveau, Ronfard, & Cui, 2017; Flynn & Smith, 2012; Paulus, Kim, & Sodian, 2015; Ronfard & Harris, 2018). In the present study, we investigated easy to acquire, developmentally appropriate, rewarding, causally unambiguous, accurate, and easily verifiable information. It is an open question whether the mechanisms for transmission of this type of information would be the same as for information that is causally opaque, inefficient or irrelevant (e.g., Burdett, McGuigan & Harrison, 2018; Corriveau, DiYanni, Clegg, Min, Chin, & Nasrini, 2017; Lyons, Damrosch, Lin, Macris, & Keil, 2011; Ronfard, Was, & Harris, 2016), socially conforming and more frequently endorsed (e.g., Morgan, Laland, & Harris, 2015), or tabooed (e.g., Seehagen, Schneider, Miebach, Frigge, & Zmyj, 2017). It would also be important to further investigate what is meant by transmission in this paradigm, i.e. whether the children are demonstrating what they can do, or that they know the rules,

to show what they themselves have learnt, or to explicitly teach someone else. These are among the exciting questions open for investigation.

Like Vredenburgh at al. (2015), we focused on 2-year-olds as the youngest group previously shown to engage in active cultural information transmission, yet a rarely studied population compared to a large body of research with preschool and elementary school children. We still know very little about the developmental trajectory of cultural information transmission in children as they navigate the social world, as well as the extent of the claims made by the *PP* accounts in toddlers, rather than infants or preschoolers, which should be addressed in further research. As we set out to investigate children's selectivity in social learning, we would like to bear in mind that within a complex, dynamic, self-organizing developmental system (Smith & Thelen, 2003), mechanisms are constantly changing. It is plausible that while we showed the parsimonious outcome of the present study's manipulation with two-year-olds, later in development this may change. Understanding when and why such a change occurs is an avenue open for further research.

Overall, our study provided an ecologically valid manipulation of pedagogical cues and evaluated two competing accounts of their role in the learning and transmission of information in toddlers. In our paradigm, children were not influenced by the context of the demonstration, but instead by the properties of the actions themselves, favoring actions that are easy to perform, require less effort, have a higher probability of achieving the desirable outcome, and result in a rewarding sound most readily. What we can conclude is that we do not have support for *PP*, as this view would assume that pedagogical cues should not only have a positive effect on transmission when manipulated alone, but that they should also override other cues, neither of which we

were able to show in our two experiments. This study contributes to our understanding of the factors affecting information transmission in early childhood.

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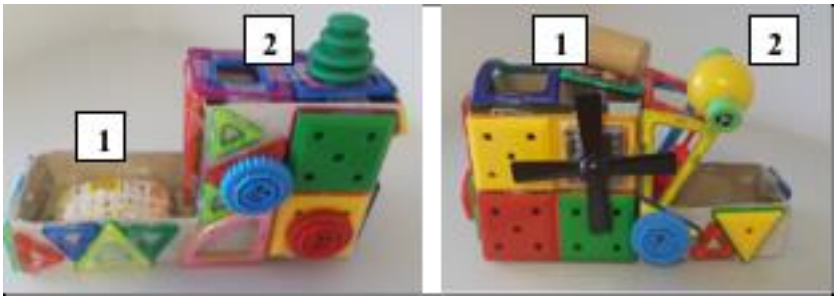
Figure 1:

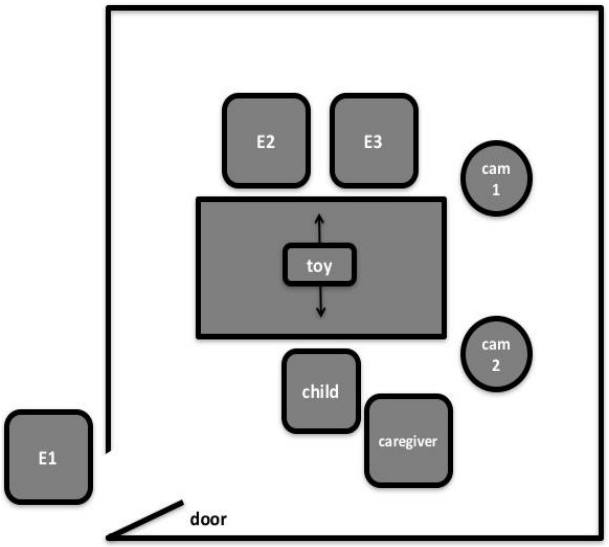
Experimental stimuli, setup and procedure

1a: Examples of stimuli (toys used in Experiment 2)



Toy1: two simple actions (button press on yellow button at the bottom (1) and the green button on the top (2) to elicit the sound); Toy 2: two complex actions (wooden toy (1) is pushed through the opning at the top of the toy to press the button to elicit the sound; plastic toy (2) is pulled out and shaken to elicit the sound)

1b: Schematic of the experimental setup



1c: Experimental procedure

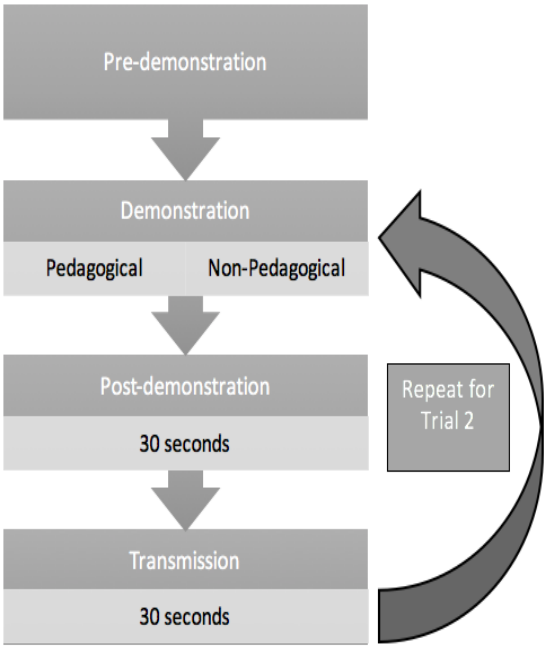
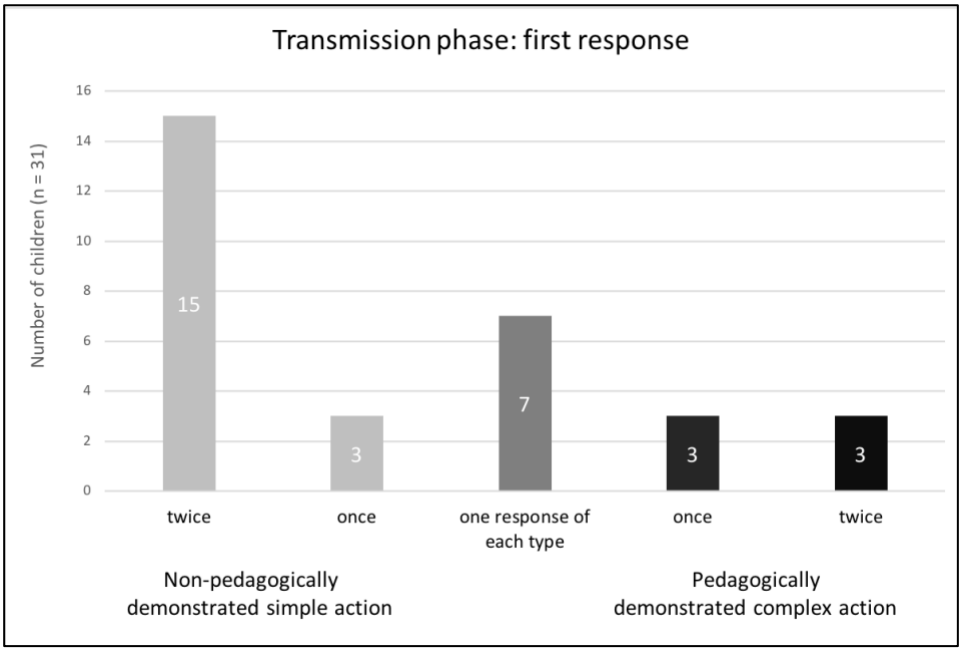


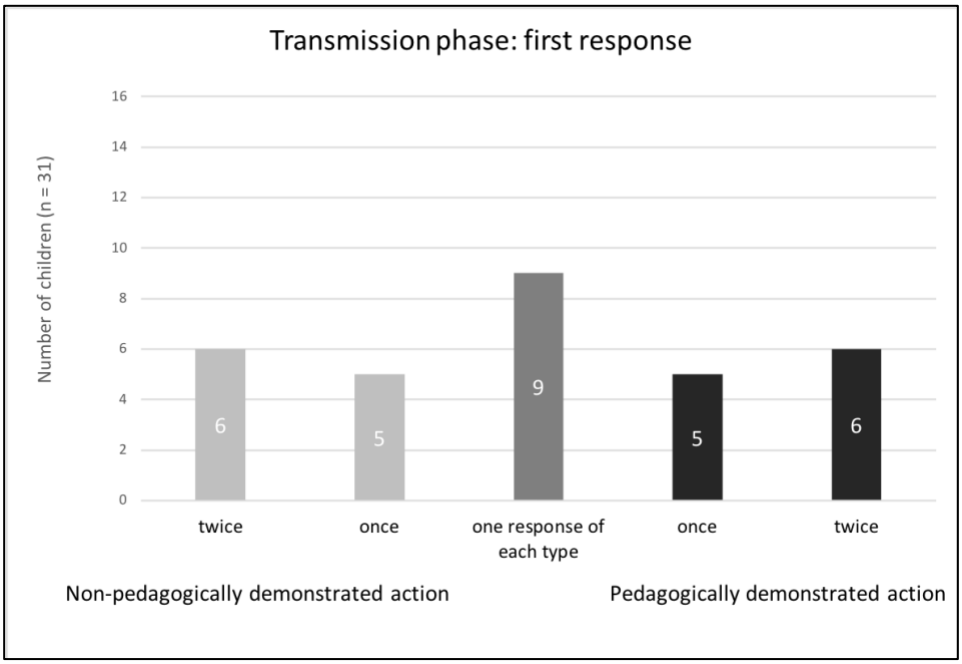
Figure 2:

Distribution of first responses at the transmission phase

2a: Experiment 1: distribution of first responses at the transmission phase across the two trials



2b: Experiment 2: distribution of first responses at the transmission phase across the two trials

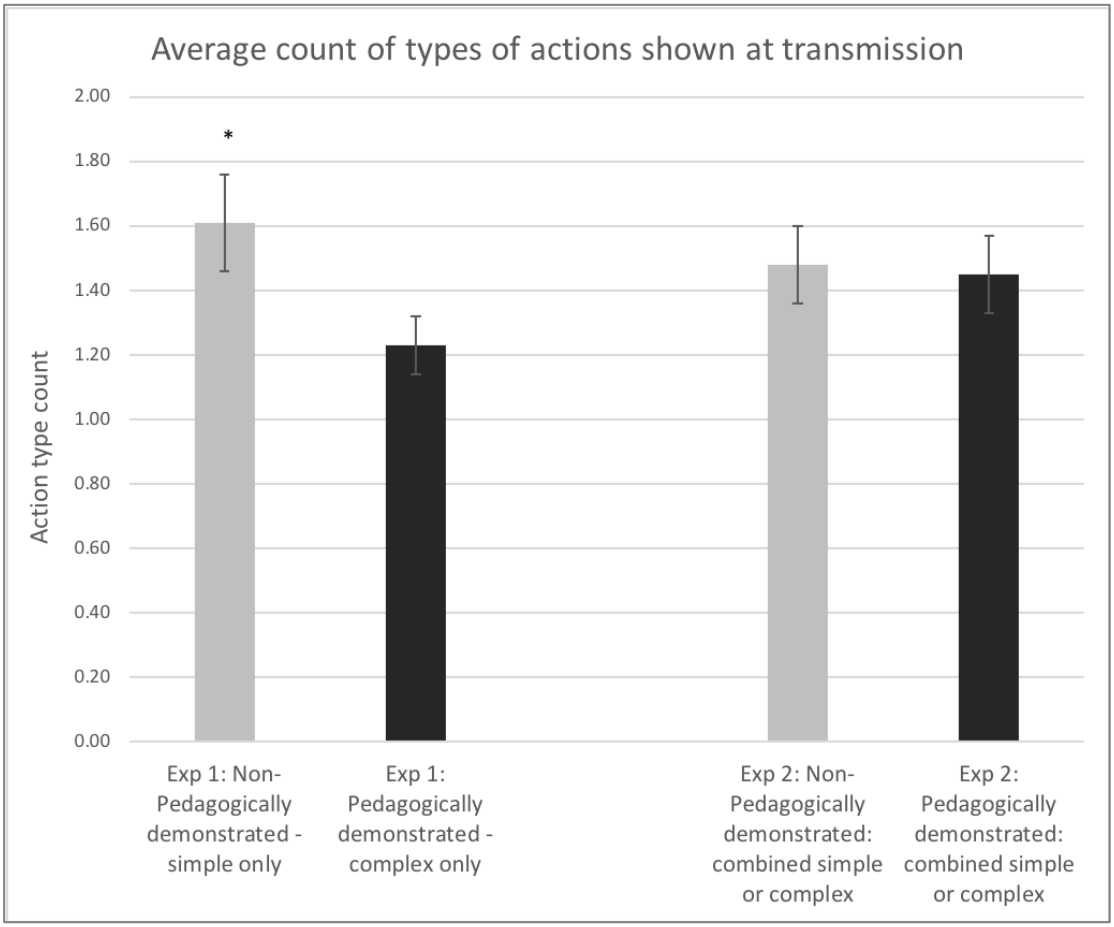


Note: The distribution of first responses to the ignorant adult's request across both transmission trials. From left to right, the responses are ordered by frequency and exclusivity; the number of children whose first response was only the non-pedagogically demonstrated action (both times or once only), to those whose first response was mixed (one of each type), to those whose first response was the only pedagogically demonstrated action.

Figure 3:

Average count of types of actions shown at transmission

Average count of different types of actions shown at transmission phase during both experiments, including pedagogically demonstrated actions and non-pedagogically demonstrated actions.



Note: Bars indicate standard errors; * $p < .05$

Supplementary materials

Durations

We measured duration of actions in both experiments as this was a key variable in Vredenburgh et al. (2015), however, we did not report duration of actions in Experiment 1 as it was confounded by our manipulation of complexity (see below).

Experiment 1

Post-demonstration

Duration of actions. Children spent significantly longer executing the complex pedagogically demonstrated actions than the simple non-pedagogically demonstrated actions ($t(52) = 4.84$, $p < .001$).

Transmission

Duration. Children spent an equal amount of time attempting either action ($t(30) = 0.53$, $p = .60$, paired t-test).

Discussion. We found no differences in how long children spent on showing the actions at transmission, while at post-demonstration children spent significantly more time executing the more complex pedagogically demonstrated actions than the simpler non-pedagogically demonstrated actions. We are cautious in interpreting any difference in durations for this manipulation due to the differing lengths of time it takes to perform the two actions, and the difference in achievability of the actions.

Children attempting both actions

It is worth noting that in our study the majority of children performed both actions at transmission episode (81% of children), whereas Vredenburgh and colleagues found that fewer children performed both actions (27% of children). This suggests a difference at the transmission stage, with the children in our study interpreting the request of the adult as ‘show me everything you can do with this toy’, and the children

in the study by Vredenburgh and colleagues interpreting this as ‘show me the right thing to do with this toy’. Notice that there were differences in the exact prompts given by the experimenters in the two studies (current study: ‘Can you show me how to play with it?’; Vredenburgh et al: ‘What is this? What does this do?’). However, there is nothing in the content of these questions that suggests more or fewer possible actions on the toy. It is therefore unlikely that these differences might account for the observed differences in action performance. Furthermore, one of the main outcomes of interest was the first transmitted action, and that should be unaffected by how many actions the child chose to perform overall.

Discussion Chapter

I. Main findings

The present thesis addressed three research questions centred on an overarching theme – the active role of young children in acquiring and transmitting information in social contexts. Three experimental chapters comprising six experiments explored infants' (11-24-month-olds') sensitivity to the informative potential of their social partners, active and selective information seeking in situations of epistemic uncertainty, and their preferential information transmission choices. While the first two studies investigated infants' active role in social knowledge exchange processes by exhibiting epistemic vigilance to the information they receive and actively seeking information from social partners, the focus of study 3 turned from the child as a solicitor of information to the child as a source of information.

Experimental Chapter 1 presented a study designed to answer the first research question: *Do preverbal infants actively respond to epistemic violations of expectation with social referencing behaviour?* 11-month-olds and their primary caregivers saw images of familiar objects presented on the screen. Caregivers provided either congruent, incongruent, or no labels to these objects. Experiment 1 of this study found that infants referenced their caregivers more when the caregiver provided incongruent labels to familiar objects repeatedly and in a consistent manner. When caregivers were sometimes accurate and sometime inaccurate in their labelling testimony, in experiment 2, infants referred to them equally often across these mixed trials, but not during the no label trials. Such indistinguishable responding to both congruent and incongruent labelling was also the case in the preliminary experiment (reported in the supplementary

materials). These results suggest that preverbal infants differentially responded to epistemic violations of expectation upon receiving unreliable labelling testimony from their caregiver. Importantly, they responded with an active communicative signal that was developmentally available to them – social referencing – thus supporting its epistemic function.

Experimental Chapter 2 presented a study designed to answer the second research question: *Do preverbal infants use social referencing to seek information from more knowledgeable adults in a situation of referential uncertainty?* In study 2 (Bazhydai, Westermann, & Parise, 2020), 12-month-old infants were placed in a situation of referential uncertainty: not knowing the answer to the posed question about a novel object-referent relationship. Infants were familiarised with two informants, one who was knowledgeable about object labels and the other who was not. At the test phase, when they faced epistemic uncertainty, infants actively and selectively used social referencing as a communicative tool in presence of potentially helpful social partners, proving themselves capable of identifying the best sources of information by selectively seeking epistemic input from previously knowledgeable informants. Social referencing emerged here as an information seeking communicative signal, actively used by preverbal infants before pointing which was previously considered to be the earliest onset of interrogative communication.

Experimental Chapter 3 presented a study designed to answer the third research question: *Do toddlers preferentially transmit information that was taught to them in an explicitly pedagogical context or information that was easier to demonstrate but not taught pedagogically?* In study 3 (Bazhydai, Silverstein, Parise, & Westermann, 2020), 24-month-olds were taught two novel actions by two experimenters. In experiment 1, one action was more complex but demonstrated in an explicitly pedagogical manner,

while the other action was less complex but demonstrated non-pedagogically. We investigated whether and how social (pedagogical communication) and non-social (action complexity) cues, or factors, affect child-led information transmission. Upon learning both actions from live demonstrations, children were presented with a choice which action to teach to an ignorant adult. Children preferentially transmitted simple non-pedagogically demonstrated actions over pedagogically demonstrated complex actions. When both actions were matched for complexity, in experiment 2, there was no evidence of preferential transmission of pedagogically demonstrated actions. We interpret the results from the perspective of the cue combination process, such that active and selective weighting of non-social and social cues guides children's knowledge transmission process. Having considered both types of salient cues during the learning phase, two-year-olds shared less complex information with an ignorant learner, while pedagogical cues, despite their proposed privileged status in learning, here had no effect on transmission choice. Overall, this study highlights that children at this age engage in emergent teaching using demonstration as a strategy to transmit pertinent and weighted information to less knowledgeable others.

Across all three studies, children were exposed to unexpected or competing sources of information during their interaction with social partners, and thus faced dilemmas which they had to resolve. The broader aim of this thesis was to investigate infants' active role in the knowledge exchange process through measuring behavioural responses to these various epistemic dilemmas. Three different situations of uncertainty were explored, ranging from the state of not knowing to having to choose between different possibilities. In study 1, when 11-month-old infants' social and epistemic predictions were violated, they attempted to resolve incongruency by referencing their trusted social partner. In study 2, when 12-month-olds lacked information they were

unable to obtain independently, they referenced social partners who proved best equipped to help resolve referential uncertainty. In Study 3, when 24-month-olds had to adjudicate between competing cues present when they learned new information in deciding what information to transmit to an ignorant social partner, they chose to preferentially transmit less complex information. Thus, in all three studies, various situations of epistemic uncertainty prompted infants to exhibit their active role in knowledge acquisition and transfer.

In sum, this thesis demonstrated young children's use of communicative skills to obtain knowledge and propagate it further. Embedded in complex social environments where knowledge can be not only passively observed, but also solicited and shared in deliberate ways, infants emerged as active agents making decisions as to what information to seek from others and what information to give to others. The next section discusses major theoretical implications of this research.

II. Theoretical contributions: Active information seeking

Broadly, this thesis contributes to the conceptualisation of social learning as an integral part of active learning by showing that from early in development, children can guide their own knowledge acquisition in social contexts. Active social engagement is an effective way for children to self-direct their learning about the world. Effective knowledge transfer via social communication necessitates that both the 'knower' and the 'learner' are actively involved in the process, and thus the 'learner' can select when to learn from others, who to learn from and what to learn (Baldwin & Moses, 1996; Strauss et al., 2014). Contrary to the influential proposals that before their second year of life, infants are merely good passive consumers of information but not seekers of information (Baldwin & Moses, 1996; Schaffer, 1984, 1989), this thesis demonstrates that as participants in social knowledge exchange, infants use social referencing as an active communicative and information seeking signal, show sensitivity to the epistemic social environment, and exhibit curiosity in social learning. The following sections reflect on the theoretical contributions that studies 1 and 2 make in these domains.

II.i. Social referencing as communication and information seeking

Research reported in studies 1 and 2 features the emergence of infants' interrogative stance – active communication and information seeking in knowledge acquisition – as a prominent strategy for social knowledge transfer, providing a crucial insight into the ontogeny of this cognitive process (Butler, 2020; Begus & Southgate, 2018; Harris et al., 2017; Lucca, 2020; Ronfard et al., 2017). Prior to the emergence of language, non-verbal communicative cues serve an information seeking function and enable active social learning, such as requesting pertinent information about the immediate environment from someone who can be regarded as knowledgeable about it.

Among social strategies to obtain information from others in response to epistemic uncertainty, this thesis focused on the early developing social referencing behaviour. Social referencing has been classically defined as infants initiating looks at others to seek their situational appraisal to help the infant determine their own behaviour towards it. This thesis proposes that social referencing is also a communicative and information seeking behaviour that preverbal infants use when facing epistemic uncertainty.

Previously, the development of pointing has been regarded as the onset of interrogative communication (Begus & Southgate, 2012; Kovács et al., 2012; Southgate et al., 2007) and a preverbal behaviour of supreme importance to language development (Bates, 1979; Colonnesi et al., 2010; Werner & Kaplan, 1963). To understand its underlying cognitive process, it has been previously asked whether infants' understanding of active communication during social knowledge exchange might be already present before they are able to produce pointing gestures. For example, a study of pre-pointing 9- and 11-month-olds showed that infants are sensitive to the communicative function of pointing (Krehm et al., 2014). When infants start using this gesture, it may reflect their attempt to transfer information rather than, as previously suggested, merely initiate joint attention (Liszkowski et al., 2006, 2008) or initiate pointing without proper consideration of a social partner's attention (D'Entremont & Seamans, 2007). While pointing is an important milestone in infants' communicative and information seeking behaviour, social referencing has been theoretically proposed to serve the same function earlier in development (Begus & Southgate, 2018; Harris & Lane, 2014). The results presented in this thesis provide evidence for this proposal. Before producing more complex and unambiguous communicative signals, preverbal and pre-pointing infants nevertheless showed active information seeking though the means already developmentally available to them, even if such signals may not yet be

readily interpretable by their social partners as a request for information in the same manner that a point or a question would be later in development. This 'interrogative social referencing' exists in parallel with affective social referencing which developed to seek social and emotion cues from social partners in situations of affective uncertainty (Clément & Dukes, 2017; Feinman, 1982; Walden & Ogan, 1988). Furthermore, the results are in support of the expertise rather than the comfort-seeking account of social referencing (Feinman et al., 1992; Stenberg, 2009, 2013) and crucially expand our understanding of social referencing behaviour as part of epistemic (rather than the more thoroughly explored in infancy emotional) development (Campos & Stenberg, 1981; Sorce et al., 1985; Stenberg & Hagekull, 2007; Striano et al., 2006).

While uncertain situations have been previously shown to increase infants' attention to social partners who provide incorrect or incongruent testimony (Brooker et al., 2013; Galazka, Gredebäck, & Ganea, 2016; Koenig & Echols, 2003), studies 1 and 2 demonstrate that such situations uniquely prompt infants to generate communicative social looks (see also Dunn & Bremner, 2017; Mireault et al., 2014; Walden et al., 2007). In this thesis, we manipulated epistemic uncertainty in two different ways to measure social referencing in response: semantic and social VoE (study 1) and referential uncertainty (study 2). While we measured the same behaviour, we argue that two different situations warrant slightly differing interpretations of the meaning of social looks.

Our VoE scenario combined two sources: object-referent mismatch (semantic incongruency) and the unexpected behaviour of the caregiver who provided incorrect labels. This presented an interesting challenge for interpreting infants' looking since in classic, non-social (e.g., core knowledge) VoE paradigms, longer looking at objects would be typically interpreted as surprise (for reviews see Sim & Xu, 2019; Stahl &

Feigenson, 2019), and looking at people while witnessing VoE event as sharing that surprise with others by establishing joint attention (Dunn & Bremner, 2017; Koenig & Echols, 2003). In our case, however, the person (caregiver) is both the source of epistemic uncertainty and the social partner with whom joint attention on the surprising event can be established, and, importantly, also the only available person who could potentially provide disambiguating evidence (unlike, for example, in Koenig and Echols (2003) study where the experimenter provides labels while the caregiver is also present, affording infant looks at either of the social partners). In this unique instance, we cautiously interpret infants' looks in study 1 as an active response to uncertainty with a communicative intent, rather than claiming that they engage in information seeking (our study 2 is better suited to make this claim). However, based on our results in both study 1 and 2, we argue that social looks and looking duration are inherently different, in that social looks are communicative in nature, while duration of looks, even when applied to a social situation, such as looking longer at a social partner, likely underlies lower-level attentional processes.

As the nature of surprise response, especially when evoked by other people, remains an important and open question, these looks can be caused by confusion, interest, attention sharing, or information seeking. Addressing this question, Sim and Xu (2019) present a well-articulated argument that when confronted with VoE events, infants engage in sophisticated statistical inference process, considering both the probability of an observed event and alternative hypotheses that could account for it, thus providing themselves with potentially new learning opportunities for belief revision. In this sense, an unexpected event leads to infants engaging in curiosity-driven learning to explore and accumulate new evidence (e.g., Stahl & Feigenson, 2015, 2017).

To provide crucial evidence in support of this claim, future studies of social referencing in response to VoE should also test infants' subsequent learning.

Additional evidence that social referencing may not be indexing merely passive surprise expression comes from a study of humour perception in preverbal infants (Mireault et al., 2014). In a similar to our study 1 situation of epistemic uncertainty, when infants witnessed absurd humorous events such as an experimenter wearing a red ball on her nose, 6- and 12-month-olds perceived these events as humorous (judged by their smiling and laughing at the events) without first seeking parental affective guidance. Thus, infants of similar age to those in our study 1 did not spontaneously seek caregiver's cues during epistemic uncertainty, nor were they more likely to share with their caregivers their own appraisal of the situation when it was ambiguous than when it was ordinary. This is in contrast to our study 1, where a potentially humorous, absurd event (calling a dog a cat) prompted increase in social referencing. However, after referring to a smiling parent (whose affective signalling was not contingent on infant generating a look at them), both 6- and 12-month-olds were more likely to smile at the event, suggesting that they were nevertheless influenced by affective cues even though they did not seek them in the first place. Since we did not measure infants' use of caregiver's cues in response to their social looks, to address this limitation, future research, as noted above, would need to design a paradigm to test infants' learning outcomes.

The discussion above focused on trying to derive the meaning of social looks in response to epistemic uncertainty, which may range from lower level attentional to higher level conceptual processes. The associative learning mechanisms are hard to completely rule out in any given study, especially when the participants had a full year of the learning experience, both in conceptual and epistemic domains. In our study 1,

some of the lower-level explanations can be ruled out since the caregiver followed precisely controlled instructions for their utterances in respective conditions, and the exploratory coding of caregiver responsivity did not reveal systematic differences in their response to infants' social looks. Still, more subtle cues have not been controlled for, such as pitch, bodily language, or proximity between caregiver and infant as a function of condition. Similarly, our study 2 was able to directly address several alternative 'lean' explanations, such as infants' potential preference for the experimenter versus the caregiver due to the associated relationship between an unfamiliar adult in a new environment – since infants met two unfamiliar adults whose identity, order and number of utterances and sides at which they were seated were controlled for. Still, the preference for Informant may have been formed due to other associated features which we were not able to control for given the live social interaction nature of the manipulation, e.g., presence of gestures, subtle bodily movements, confidence or pitch of their respective utterances. The studies in this thesis are therefore unable to make a strong claim in favour of either domain-general or domain-specific mechanisms.

In sum, we show that before their first birthday, preverbal infants spontaneously direct their looks at people who are best suited to resolve the epistemic uncertainty, substantially extending previous findings of selective information seeking in preverbal infants (Goupil et al., 2016; Kovács et al., 2014; Vaish et al., 2011). This thesis therefore contributes to characterising the repertoire of infants' looking responses and their underlying cognitive mechanisms in epistemic uncertainty (Aslin, 2007; Bergmann et al., 2019; Dunn & Bremner, 2017; Sim & Xu, 2019).

II.ii. Development of selective active social learning

This thesis contributes to understanding the ontogeny of selective active social learning by elucidating preverbal infants' sensitivity to their social partners' ability to provide reliable information. While an extensive body of research on selective trust focused on three-to-five-year-old children, less research has been dedicated to its earlier development (Koenig & Harris, 2005; Koenig & Harris, 2007; Nurmsoo et al., 2010; Poulin-Dubois, & Brosseau-Liard, 2016). As active information solicitors, infants in studies 1 and 2 exhibited early signs of epistemic vigilance in social learning by discriminating between social partners' accurate, consistent and competent information provision.

Studies of selective trust in children under the age of three report inconclusive results. In most studies, infants (typically 18-24-month-olds) are introduced to a single experimenter playing a role of either a reliable or an unreliable informant. Upon an opportunity to encode the experimenter's epistemic status, infants learn new labels selectively from a previously reliable experimenter (Crivello et al., 2018; Koenig & Woodward, 2010; Krogh-Jespersen & Echols, 2012). However, other reports showed that two-year-olds did not selectively endorse testimony provided by a more accurate social partner (Ganea, Koenig, & Millet, 2011; Hermes, Rakoczy, & Behne, 2019), or were unable to make person-specific attributions of reliability and therefore did not subsequently show selectivity in learning from a reliable informant (Schmid, Mani, & Behne, 2019), which may be related to toddlers' lack of advanced cognitive and theory of mind skills.

Do preverbal infants have the ability to encode a speaker's epistemic status (Harris, 2019)? Research employing different paradigms with infants demonstrated that even 8-month-olds show sensitivity to informative reliability cues in a social context

(Tummeltshammer et al., 2014), and that 11-month-olds selectively expect to learn from informative rather than non-informative speakers (Begus et al., 2016). In live interaction studies, when presented with a single experimenter testimony, one-year-olds pointed more to a novel toy when the experimenter was previously reliable rather than unreliable or simply uninformative (Begus & Southgate, 2012; Kovács et al., 2014; Lucca & Wilbourn, 2018). Rather than testing infants' selective label learning from either a reliable or an unreliable informant, the question in these studies with preverbal infants (as well as in our study 2; Bazhydai et al., 2020), asks in the first place whether infants exhibit the ability to encode the informative potential of the speakers. We show that 12-month-olds are indeed able to distinguish the knowledgeability cues of social partners, determine who is a better source of knowledge, and selectively refer to them when information is lacking. The methodological differences may be responsible for the inconsistencies across various studies in this line of research, some of which are discussed in the Methodological Considerations section of this chapter. To reconcile these findings with the previous body of research with preschoolers, future research should investigate if infants at this age will also subsequently learn better from more knowledgeable or reliable informants.

In our study 2, we show that infants at 12 months evaluate and encode the respective informativeness of the social partners and use these evaluations in guiding their information seeking behaviours. Thus, infants showed sensitivity to knowledge distribution among the experimenters: one as a reliable and informative social partner, and the other as a non-informative and unreliable source of knowledge about objects' labels, albeit an engaging social partner. In our study 1, we further probe the ontogeny of selective trust in demonstrating that 11-month-olds recognise when social partners are unreliable or inconsistently reliable. Upon detecting a mismatch in semantic

testimony from their primary caregivers, infants experienced a violation of expectation. We interpret these findings in the sense that they attributed default expectations of trustworthiness to their social partners and therefore selectively responded both when social partners were consistently unreliable and inconsistently reliable. Thus, in study 1, we show that infants' violation of expectation is driven by both detecting an object-label mismatch and by a previously accurate informant becoming inaccurate in their testimony. While previous reports in similar paradigms showed infants' surprise response (longer looking time) to social partners as they provided consistently unreliable or incorrect information (Brooker et al., 2013; Galazka et al., 2016; Koenig & Echols, 2003), we extend these findings by showing that younger infants attribute default trustworthiness to their social partners and are not willing to tolerate inconsistency in their testimony, despite being able to properly attend to the changes in epistemic cues. This finding sets preverbal infants apart from older children who are able to track social reliability cues and make dynamic adjustments to epistemic situations (Clegg et al., 2019; Gillis et al., 2019; Hoicka et al., 2017; Koenig & Woodward, 2010; Leech et al., 2019; Nurmsoo & Robinson, 2009; Ronfard & Lane, 2018, 2019).

While this was not the main focus of our study, we additionally explored whether infants in our study 2 also looked at the caregiver when facing epistemic uncertainty[7]. It is important to clarify that substantial looking at the caregiver was expected in the very set up of the experiment: aside from being, naturally, a caregiver

[7] We report these exploratory analyses here because study 2 is presented in this thesis in its final published form, which did not include these. We refrained from running any statistical analyses and only present descriptive results.

rather than an unfamiliar adult, she/he was the only person sitting directly across the infant rather than to the side, and the only person handling the objects and asking questions. When facing referential uncertainty (at test), the caregiver asked the key question and remained silent and gazing directly at the infant for the duration of the test trial. While the study was not designed to investigate the differences in looking at caregiver vs experimenters, construed in this way, each of the three present adults (Caregiver, Informant or Non-Informant) had a 33% chance of attracting infants' looks. This exploratory coding revealed that while infants' first looks were directed at Caregiver (M = .48) more so than at Informant (M = .32) and Non-Informant (M = .20), their total looks nevertheless favoured Informant (M = .42), rather than Caregiver (M = .34) and Non-Informant (M = .25). Thus, even after accounting for the initial looks at the caregiver, which could be expected by design as initial attention to the person who put the toys on the table, as well as who of all uttered the question and sat directly across the table, infants looked more often at the Informant as the person who could ultimately provide an answer to the question posed by the caregiver. This supports the general conclusion of the study 3 and the theoretical account that expertise rather than familiarity guides social referencing in epistemic uncertainty.

II.iii. Active social learning as curiosity

Curiosity conceptualised as self-motivated learning has recently come into focus in developmental research, emphasising its cognitive, perceptual, and computational aspects (see Bazhydai, Twomey, & Westermann, 2020; Kidd & Hayden, 2015, for reviews). This thesis broadly contributes to the literature on curiosity in the currently underexplored social learning domain, expanding this field to include infants' social interactions, and highlighting the premise that active communicative information

seeking during social interaction is one of the manifestations of curiosity (see Begus & Southgate, 2018, for a review). As a multi-sensory experience, curiosity-driven exploration encompasses visual, haptic, proprioceptive, communicative and social skills, expressed through visual and manual exploration, approaching objects or people that are of interest, as well as using social partners to solicit interesting information. With social referencing as the target infant behaviour in this thesis, it can be argued that curiosity presents itself as analogous to visual scanning in the social domain: using social gaze to obtain information from available social partners.

Several prominent theories argue for a range of cognitive mechanisms underlying curiosity. While according to the early approach rooted in behaviourism, curiosity is a natural drive akin to similar biological drives such as hunger and explained through the interplay between reflexes and external stimulus responses, the data stemming from studies 1 and 2 are better explained by a combination of incongruency, information gap, and learning progress approaches (for reviews of these approaches, see Bazhydai et al., 2019; Kidd & Hayden, 2015; Loewenstein, 1994, and the Introduction Chapter of the current thesis).

Curiosity is proposed to be triggered to process detected incongruency, such as novel, surprising or complex incoming information, in order to update existing internal representations through cognitive assimilation or accommodation processes (Berlyne, 1960; Kagan, 1972; Piaget, 1969). For instance, previous research demonstrated infants increased independent exploration of the source of unexpected events (Stahl & Feigenson, 2015; Sim & Xu, 2017). Studies 1 and 2 contribute to our understanding of infants' response specifically to epistemic uncertainty in social context, by suggesting that to resolve such uncertainty, preverbal infants tend to ask others for help through explicit information seeking communication. Results from study 1 go beyond previous

reports showing that infants turn to others when events violate their expectations about physical properties of the world (Dunn & Bremner, 2017; Walden et al., 2007), and extend findings from studies with older infants showing longer looking at social partners following unreliable testimony (Brooker et al., 2013; Koenig & Echols, 2003): when a social partner offered inaccurate information, infants not only redirected their attention to them from the incongruent stimulus, but also selectively referred to them communicatively, suggesting early signs of explanation or clarification seeking. In study 2, in line with previous reports (Goupil et al., 2016; Vaish et al., 2011), when asked surprising questions to which they were unable to obtain an answer independently, infants generated social looks at the best source of information to obtain such an answer.

According to the information gap approach (Loewenstein, 1994), curiosity is a process allowing to overcome one's lack of knowledge on a particular topic, by closing the gap between the current knowledge and desired knowledge state. Studies with adults have shown that curiosity is the lowest when individuals have either too little or too much baseline knowledge about the topic (Gruber et al., 2014; Kang et al., 2009). This thesis's study 2 could also be explained by the information gap approach, if an assumption is made that deliberate, conscious understanding of the existing information gap is not necessary. If infants detected a gap in their existing knowledge and the question posed to them during the test phase of the procedure (that they do not have an answer about the referent-object relationship, "Which one is the [pseudoword]?"), their curiosity may have driven them to seek such answer from the knowledgeable social partner. It remains unclear, however, if the classically defined information gap approach, which is likely to involve metacognitive abilities, is applicable to preverbal infants' cognition. In addition, there is a lot of overlap between the information gap and

the learning progress approach, which, on the contrary, has been actively investigated in infancy.

Learning progress theories propose that curiosity arises to maximise knowledge acquisition and reduce epistemic uncertainty through seeking out learning experiences that lead to a systematic reduction in prediction error. Studies showed infants' reduction in curiosity-driven visual exploration when presented information was either too predictable or too complex for them to grasp (Kidd, Piantadosi, & Aslin, 2012), interpreted as infants attending to events that have the best chance to facilitate the most efficient and optimal learning progress. Computational and developmental robotics research (e.g., Oudeyer et al, 2016; Twomey & Westermann, 2018) operationalise this approach by leaving out completely the need for subject's metacognitive awareness of the underlying processes. While the majority of learning progress investigations focused on independent curiosity-driven exploration, social learning also plays a role in efficient knowledge acquisition. For example, Forestier and Oudeyer (2017) reported that a robot learning to use novel tools and produce novel sounds used both autonomous exploration and sought out the "caregiver's" involvement to aid its learning process. In studies 1 and 2 of the current thesis, infants' motivation to turn to social partners can therefore be explained by the underlying learning progress motivation: as useful sources of pertinent knowledge, social partners may be both the objects of infants' curiosity and the social tools used to obtain information to satisfy curiosity. In this thesis, we demonstrate how this process may work in preverbal infants, contributing to general understanding of the early pre-cursors that lead to more sophisticated question-asking in later development (for reviews, see Butler, Ronfard, & Corriveau, 2020; Lucca, 2020; Ronfard et al., 2018).

III. Theoretical contributions: Active information transmission

Broadly, this thesis contributes to the literature demonstrating that active social learning is a bi-directional process, where infants are more than mere recipients of information, but rather its active solicitors and propagators. If infants take an active information seeking stance as they process changes in epistemic situations when they learn, do they also take an active information transmission stance? If the heuristics used by infants to seek information from social partners require no need for mentalizing capacity, are infants' heuristics for information propagation also present before reaching cognitive maturity? This section highlights this thesis's theoretical contributions to elucidating cognitive mechanisms and early behavioural manifestations of child-led information transmission as a function of the properties of information and the social context.

III.i. Development of information transmission

Little is known about the developmental trajectory of information transmission and its cognitive mechanisms (Corriveau et al., 2018; Kline, 2015; Paulus et al., 2015). The overarching aim of our investigation therefore was to advance the understanding of teaching by identifying its basic functions and building blocks which would be common to both simple and more complex forms of teaching, in line with the proposed constructionist approach (Pasquinelli & Strauss, 2018). Whereas infants aged 12 months have been shown to engage in proto-teaching by informing others when they possessed episodic information their social partners did not (Liszkowski et al., 2006, 2008; Meng & Hashiya, 2014), children aged 3 and above confidently engage in transmitting generalisable information, such as demonstrating how to play a game or how an object works. Gradually enriching their toolkit with development and language

acquisition, verbal explanations and systematic teaching adapting to the learner's needs and response become more prevalent (Strauss & Ziv, 2012; Pasquinelli & Strauss, 2018).

Only a handful of studies investigated information transmission in children under the age of three, leaving a gap in our understanding of teaching ontogeny (Ashley & Tomasello, 1998; O'Neill, 1996; Vredenburgh et al., 2015). Contributing to this body of research, we broadly conclude that using a minimalist experimental paradigm to model naturalistic social engagement, our study 3 (Bazhydai, Silverstein et al., 2020) suggests that toddlers were able to engage in solicited information giving and used action demonstration as their strategy to transmit information when queried by an ignorant social partner. Through their active demonstrations, children shared functions of a novel toy (though, overall, they preferred to transmit the simpler rather than more complex information). Therefore, according to the adopted in this thesis classification (Strauss & Ziv, 2012), two-year-olds engaged in *emergent teaching*, typically characteristic of three-year-olds, rather than in the *proto-teaching*, as observed in preverbal infants. This is further supported by the fact that infants eagerly responded to the generic prompt for information from a naïve adult ("Can you show me how to play with this toy?") and ultimately demonstrated all actions they learned how to perform on a novel toy. It could be argued, however, that according to the operationalisation of generalisability in NP (Csibra, 2010), both actions in this study were specific (e.g., this particular button press makes a particular sound), rather than kind-generalisable (e.g., this kind of object is used to serve this kind of function). At the same time, from another perspective, if demonstrating the rules of a particular game can be viewed as generalisable knowledge that preschoolers often engage in teaching to others, it would also apply to demonstrating the functions on a particular cultural artefact – a toy

affording a range of functions. To expand on this reasoning, if we teach someone that Minsk is the capital of Belarus, is this specific or generic knowledge? The information is specific (but not episodic; that is, unless the existing political unrest does not lead to a change of the country's name or its capital name, of course). Nevertheless, for someone to relay this information would be considered a teaching episode. Similarly, preschoolers teaching the game rules are conveying information specific to this game, yet, the normative nature of such episode makes it a teaching episode. To lend stronger support for the conclusion that we observed emerging teaching in two-year-olds, future research would need to investigate toddlers' preferential transmission of specific versus generic information, as well as their response to differently phrased prompts from a naïve learner (distinguishing between requests evoking normative behaviour by asking for generalisable vs specific information), as well as spontaneous teaching propensity.

III.ii. Information complexity as a non-social factor for transmission

The interpretation that two-year-olds transmit generalisable, non-episodic information is in line with the results reported by Vrebenburgh et al (2015), but contrary to the report by Ashley and Tomasello (1998) that studied the same age group. This may be due to important methodological differences between the studies. First, Ashley and Tomasello studied peer-to-peer teaching, rather than toddlers' propensity to inform an ignorant adult. In the context of their social cooperation task, toddlers may have behaved differently than when a friendly adult experimenter asked them to demonstrate the actions of the toy they learned (as in Bazhydai, Silverstein et al., 2020, and Vredenburgh et al., 2015). Second, the task used in our study was relatively unsophisticated (and similar to Vredenburgh et al., 2015), in stark contrast to the difficult, multi-step task used by Ashley and Tomasello (1998), where children may

simply not have had the cognitive and motor capacities to succeed in the first place. Indeed, it has been previously found that toddlers fail to imitate an action that they cannot motorically achieve (Paulus, Hinnius, Vissers, & Bekkering, 2011). Thus, it is likely that developmental motor and cognitive deficiencies precluded children in the Ashley and Tomasello's study to transmit complicated sequences of actions to teach another child, in turn precluding the authors to conclude that toddlers, like preschoolers, can teach generalisable rather than merely episodic information. Although the more complex actions presented toddlers with a relative challenge in execution, in our study, there is no evidence that struggling to achieve the outcome of the relatively more complex action affected children's transmission choice: while simple actions were taught by children preferentially, both simple and complex actions were eventually transmitted. This is in line with the research reported by Nielsen (2006) where 24-month-olds often failed to imitate an action (to achieve its outcome) but actively persisted nevertheless, which was interpreted as evidence for toddler's habitual, successful and deliberate imitation (after Call & Carpenter, 2002).

Our study was rooted in the premise that according to NP, complex action, despite being cognitively and motorically more taxing than the more simply executed and thus more salient action, would be more likely transmitted since it was paired with pedagogical cues in Experiment 1. We, however, chose to manipulate information complexity using a dichotomous approach (complex-simple), which was admittedly a substantial simplification of the complexity dimension. Similarly, though, the pedagogical demonstration manipulation was also schematised. It remains possible that a different, more nuanced manipulation of both complexity and pedagogy variables may yield a different result, especially if future studies could operationalise these as graded dimensions rather than dichotomies. On the other hand, we could have made both

manipulations even more extremely polarised in order to isolate the effects, e.g., by having the non-pedagogical demonstration occur without any interaction with children, or by making complex actions even more pronounced, similar to the multi-step apparatus operation (e.g., Ashley & Tomasello, 1998). Future research should focus on systematic exploration of the interaction between social and non-social salient cues.

With the chosen complexity manipulation, nevertheless, the preferential transmission of simple actions lends support to the principle of utility calculus demonstrated in older children's information transmission studies (Bridgers et al., 2020; Gweon & Schulz, 2019). According to this approach, simplicity as a rational and efficient choice outweighs the unnecessary complexity, such as when an equally rewarding outcome can be achieved without having to perform a more complex, albeit enhanced through the explicitly pedagogical demonstration, action. It may be concluded that two-year-olds preferred simple actions because they were more confident in performing them for an ignorant adult. In this sense, when having to adjudicate between multiple sources of information in choosing what information to propagate, two-year-olds rely on simpler heuristics. While complex and cognitively opaque information is more likely to be transmitted in older children and adults (Caldwell, Renner, & Atkinson, 2018; Ronfard & Harris, 2018), this does not appear to be the case in younger children. In our study, toddlers chose to preferentially transmit an action that was easier to accomplish (hence, they were able to confidently demonstrate it to an ignorant partner) rather than the harder-to-demonstrate action that bore the weight of social normativity and cultural significance. It is also possible that two-year-olds are simply not sensitive to cultural saliency cues, with such sensitivity emerging in preschool years along with the theory of mind skills.

III.iii. Mentalising and normativity as social factors for transmission

Contributing to the operationalization of teaching in early development, our results suggest that two-year-olds engage in proto-mentalistic and proto-metacognitive transmission, rather than support the theory of mind (ToM) or normative conceptualisation of teaching. As such, we show support for the behavioural and cognitive rather than the mentalistic approach to teaching conceptualisation (see section III.i of the Introduction Chapter for a review).

It is uncontested that children's understanding of teaching and of themselves as teachers is not available until the ToM milestone is reached in later development (Corriveau et al., 2018; Pasquinelli & Strauss, 2018), when children start to appreciate teaching as a special communicative act that leads to a change in beliefs (Gelman et al., 2013; Rhodes et al., 2015; Sobel & Letourneau, 2016). Less is known about infants' understanding of knowledge distribution in teaching interactions (Ronfard et al., 2018; Ziv, & Frye, 2004; Ziv et al., 2016) and the notions of intentionality and rudimentary, proto-mentalising capacities in infancy are a subject of debates (Gergely et al., 1995; Király et al., 2018; Setoh et al., 2016). Our study suggests that teaching in two-year-olds may happen without setting intentions and prior to their ability to demonstrate the ToM competence through the false belief tasks. We have no evidence to suggest that children in our sample realised that they possessed unique transferable knowledge which the ignorant adult did not have, or that the children's choice of actions was a function of their deliberate reasoning about the nature of their own communicative behaviours or about others' minds.

However, the minimalist paradigm we employed nevertheless allowed elucidating early emergent teaching in this age group – one that does not presuppose

complex social cognition but rather requires "only a certain degree of acceptance of the learner's attention, with no specific modification of their own behaviour needed" (Pasquinelli & Strauss, 2018, p. 737). This observed behaviour fits well with the definition adopted in the fields of cultural evolution and animal cognition (Caro & Hauser, 1992), which leaves out completely the ability to make inferences about the mental state of others as a prerequisite for teaching. Instead, teaching is defined as a teacher's behavioural adjustment in the presence of a naïve learner, without immediate benefit for the teacher, in order to provide, through behavioural reinforcement strategies, an experience or an example to the learner, as a result of which the learner is able to master a skill or obtain such knowledge which would be otherwise unobtainable or obtainable only later in life. The performance of toddlers in the current study provides an example of such teaching. In this way, while preschoolers use demonstrations and verbal explanations (such as teaching and reinforcing game rules), two-year-olds teach primarily through demonstration of how something works, and works reliably well, but without any metacognitive insight into their teaching.

In addition to reliance on ToM capacity, teaching has been dubbed a highly normative enterprise (Pasquinelli & Strauss, 2018), with generalisable, opaque, obscure and culturally normative information more likely to be transmitted (Ronfard & Harris, 2018). For example, preschool age children spontaneously correct and teach actions that violated the rules of the game, use normative language, and enforce social norms (Köymen, Lieven, Engemann, Rakoczy, Warneken, & Tomasello, 2014; Rakoczy et al., 2008; Rakoczy & Schmidt, 2013, Schmidt et al., 2011). Furthermore, children often regard social learning context as generally norm inducing, indiscriminately to the presence or absence of explicit pedagogical or other normative cues (Casler, Terziyan, & Greene, 2009; Schmidt, Butler, Heinz, & Tomasello, 2016).

However, such normative conceptualisation of teaching in children under the age of 3 has not been explored.

In our study 3, normative motivations do not seem to be the driving force in two-year-olds' information transmission. Despite one action demonstrated in an explicitly pedagogical manner and the other not, two-year-olds were eager to transmit all knowledge they gained from both demonstrators, with 81% of children performing both actions. Thus, rather than interpreting the solicitation of information as 'show me the *right way* of playing with this toy', children seem to have interpreted the ignorant adult's request as 'show me *everything* you can do to play with this toy'. Similar observations have been made of 3-year-olds engaging in undifferentiated, rather than selective, teaching, when children spontaneously chose to teach both ignorant and knowledgeable social partners, despite being able to encode their respective epistemic status (Ronfard et al., 2015).

Two-year-olds' eagerness to transmit all and every piece of information they possessed to an ignorant social partner in itself warrants further investigation. It is possible that such broad provision of information was triggered by a presence of a knowledge gap between themselves as knowers and an ignorant adult as an eager learner (Ronfard & Harris, 2018). Alternatively, it is possible that children failed to properly monitor information sources in presence of other saliency cues, such that interesting functions of the novel toys overshadowed the salience of the pedagogical cues, all while children were excited to actively and confidently demonstrate what they learned to their social partner. In this vein, research shows that children easily forget the details of how, when and where knowledge came from (Principe, Kanaya, Ceci, Singh, 2006; Taylor, Esbensen, & Bennett, 1994).

We therefore conclude that for two-year-old children, teaching may not be a special, costly, intentional, normative and metacognitive communicative act. Instead, they engage in pre-normative teaching better characterised by an urge to propagate learned information. The question of which social and epistemic factors are taken into consideration by these young teachers is open for further systematic investigation.

III.iv. Pedagogical cues in active information transmission

Broadly, pedagogical transmission has been proposed to allow for efficient transfer of generalisable, cognitively opaque cultural knowledge. Infants' sensitivity to pedagogical cues has been the focus of the Natural Pedagogy (NP) approach (Gergely & Csibra, 2009, 2011). According to NP, explicit ostensive cues signal to the naïve learner that knowledge being intentionally communicated by the teacher is important for their acquisition. Such reasoning is broadly rooted in the cultural evolutionary theories that information that is difficult to discover independently would benefit from being transmitted through explicit teaching from a knowledgeable to an ignorant conspecific (see also Thornton & Raihani, 2008). While the effect of ostensive cues on learning has been primarily investigated in preverbal infants, preschool-aged children have also been shown to infer normativity following pedagogical cues (Butler, Schmidt, Bürgel, & Tomasello, 2015).

Though NP theory has only addressed learners' passive receptivity to pedagogical cues, other proposals extended the key tenets of this theory to children's active teaching (Ronfard & Harris, 2018; Strauss et al., 2014). According to these proposals, children's sensitivity to pedagogical cues facilitate encoding of information as generalizable knowledge suitable for transmission to conspecifics. While our results showed that two-year-olds engage in propagation of generalisable knowledge that is valid beyond the current situation and specific content (i.e., novel toy's inherent

functions), the study exposed the limits of NP theory in the active child-initiated teaching domain. First, we did not obtain any evidence that the demonstrator's pedagogical cues made children encode the information they taught as preferential for transmission. Our results instead went beyond the theory showing children as pragmatic transmitters. Second, our findings are not in line with the proposal that pedagogical cues hold a privileged status in this situation. Instead, they are in line with the proposed in our paper competing cue combination account suggesting that both pedagogical cues and ease of execution may enhance the saliency of information and increase the likelihood of its learning and subsequent transmission. Nevertheless, it remains possible that two-year-olds present a special case as the developmental stage between infancy and preschool age which may display differential sensitivity to pedagogy and action complexity cues. Importantly for settling the existing theoretical debates, since only a handful of studies looked at this question, our results warrant replication and further investigation.

In support of the pedagogical approach to teaching, previous reports suggested that children themselves spontaneously use ostensive cues when teaching others, such as initiating and maintaining direct eye contact and using gestures to aid explanations (Calero et al., 2015; Calero et al., 2018; Whiten & Flynn, 2010). This has been reported as evidence in support of NP theory that ostensive cues communicate pedagogical, generalisable relevance during cultural transmission. Hence, if younger children also naturally emit such cues, this would suggest that they indeed engage in emergent teaching rather than episodic information sharing. To explore this, using data from study 3, we analysed two-year-olds' ostensive and other explicit teaching-related non-verbal

and verbal cues[8]. Specifically, we coded the number of looks children initiated at the demonstrator as they were being taught, at the post-demonstration phase when they had a chance to copy the action and explore the toy, and at the transmission phase as they taught the ignorant experimenter. In addition, we coded whether the child established joint attention to the toy with the experimenter before beginning the transmission action demonstration, and whether the child provided explicit verbal instructions or teaching cues to experimenter (e.g., labelling the object's parts (car, toy), explaining: "This is how you do it", "You put it here - then you press this button", “See?”, “Here, like that!” etc.).

Results demonstrate that children generated more social looks during the transmission (M = 3.04, SD = 1.8) than during the demonstration (i.e., learning) (M = 2.53, SD = 0.87) and the post-demonstration (i.e., toy exploration or manipulation check) phases (M = 2.35, SD = 1.23); $F(1, 59) = 7.29$, $p < .001$, $\eta p^2 = .11$; repeated-measures ANOVA. At the onset of the transmission phase, 73% of children established joint attention to the toy with the ignorant experimenter, and 33% of children used direct instructive cues when teaching the functions of the novel toys. Those ranged from saying just one word, e.g., “*This*” or “*There*”, to more elaborate interaction combining instruction and demonstration, such as this one: Experimenter: “*Can you show me how to play with this toy*?”; Child: “*Yeah*! [takes the hammer-like tool; establishes joint attention]; *put it there* [puts it in the toy’s opening and presses the button inside, looks at experimenter]; *take it down* [puts toy in second opening; looks at experimenter]”. Children’s ostensive and explicit instructive cues were not related to the outcomes of the pedagogical or complexity manipulations in the two experiments (i.e., first actions

[8] We report these exploratory analyses here because study 3 is presented in this thesis in its final published form, which did not include these results.

chosen and number of each type of actions shown). While the study's procedure precludes us from making conclusive inferences about the exact function of these behaviours, and despite the inherent limitations of this unplanned exploratory coding, it nevertheless lends additional support to the account that two-year-olds engaged in emergent teaching which, presumably without their consicous awareness, closed the knowledge gap between themselves and their social partner.

IV. Methodological considerations

The studies comprising this thesis made use of the existing replicable methodologies, as well as extended and consolidated previously reported findings from separate lines of research. As such, study 2 built on the main principles of the existing two-experimenter paradigms, which are extensively used with children over three years of age in studying selective trust. We adopted these paradigms for use with preverbal infants using a simplified contrast between an informant and a non-informant, rather than more complex contrasts, such as those manipulating the degree of the informant's reliability. This simplification allowed us to elucidate the basic cognitive mechanism which may underlie the later developing, more complex selective information seeking. Studies 1 and 3 aimed at replicating previous findings, while also making key modifications to investigate the target behaviours: e.g., extending the length of the trial in study 1 to detect spontaneously occurring social referencing (adapted from Parise & Csibra, 2012), and modifying precise utterances used by the experimenters in study 3 (adapted from Vredenburgh et al., 2015).

IV.i. Interactive nature of the design

Research on cultural information transmission benefits from creating semi-naturalistic environments in the laboratory settings (Miton & Charbonneau, 2018). The rich social context chosen to investigate the three research questions in this thesis was necessary to elucidate the core active social learning processes, but also presented additional methodological challenges as each study involved making a number of a priory decisions to shape social interactions.

Extensive procedural piloting and training of caregivers and experimenters proved essential for collecting quality data. While infants had to encode the epistemic status of all adults they interacted with, it was crucial to control for the naturally

occurring (and unrelated to the experimental manipulations) emotional expressions, eye contact, gaze direction, voice pitch, and other social cues emitted by the interactive social partners. To mitigate the effect of these potential confounds, we counterbalanced the identity of the experimenters, the sides where they sat during the procedure, and the order of who spoke or acted first, as applicable.

While training the experimenter to enable the manipulation allows standardizing the procedure, asking caregivers to do so has its notable advantages. At least for some infants, the presence of the caregiver made the laboratory testing environment less stressful. The research question of study 1 relied on the assumption that infants expected reliable information from trustworthy informants, which their primary caregivers are by default. In study 2, on the contrary, caregivers acted as impartial and genuinely unknowledgeable social partners, unable to provide helpful information to their children when they faced referential uncertainty. At the same time, by having caregivers present objects and pose the crucial questions at the test phase, we ensured that neither of the experimenters had the advantage of privileged access to the toys or through being the one verbalizing the key questions. Relatedly, despite its positive impact on ecological validity, the use of live objects presented a challenge for some infants when the toys were placed out of reach or had to be taken away. Here, again, the help of primary caregivers who knew the effective strategies for communicating with their infants was invaluable. As caregivers were instrumental to enabling the procedures in all three reported studies, unlike with trained researchers, it was impossible to rigorously control for individual differences in how they approached their task (e.g., variability in their emotional expressions, level of engagement, voice pitch, etc.). Therefore, to ensure caregivers did not systematically though inadvertently affect infants' responses, we undertook additional coding of their behaviours, such as measuring responsivity to

infants' social looks in study 1 and caregivers' own looks towards the experimenters in study 2.

IV.ii. Experimental design considerations

While the within-subject design provides a rigorous test to isolate experimental effects, our study 1 demonstrated its less than optimal suitability in interactive social learning experimental setups: as the manipulation is inherently social, infants' encoding of and reaction to inconsistent and mixed messages may lead to a different outcome. Here in study 1, our interpretation is that infants were not able to completely disengage from the previously formed social and epistemic profile of the caregiver at the onset of a new trial, instead making global inferences based on the inconsistency in labelling testimony, rather than isolating the effects of congruent and incongruent trials separately. Relatedly, while shorter trial durations, as used in cognitive and neuroscience fields, may help mitigate infants' inattention, behavioural social learning studies in infancy typically employ longer trials. For instance, in relation to study 1, previous studies investigating infants' looking response to repeated labelling events had trials lasting between 10 (Brooker & Poulin-Dubois, 2013) and 30 seconds (e.g., Dunn & Bremner, 2017; Koenig & Echols, 2003). Our choice of trial length aimed to minimize participant burden by keeping infants' attention yet allowing sufficient time to generate discrete social looks. Importantly from both theoretical and methodological perspectives, we produced converging evidence that a between-subject design is better suited to investigate infants' active communication in social learning context (for examples of between-subject designs in social learning studies, specifically testing infant-initiated explicit communicative cues, see Begus & Southgate, 2012; Koenig & Echols, 2003; Kovács et al., 2012; Vaish et al., 2011).

As relevant to studies 2 and 3, consideration was given to the single-experimenter paradigms (where participants are only exposed to one type of manipulation, such as the informant's uncontested testimony) as opposed to the two-experimenter paradigms (where participants are in an active choice situation, such as receiving testimony from two informants who differ in their labelling accuracy or their mode of teaching). While the single-experimenter paradigms may be less cognitively taxing, the dynamic two-experimenter designs with higher task demands, such as those employed in studies 2 and 3, are more powerful in eliciting the behavioural outcomes of interest. Since in such designs each participant receives both experimental conditions, the effects are easier to isolate and interpret. An additional benefit of such paradigms is that a smaller sample size is sufficient to obtain high powered results.

A number of experimental design considerations are specific to child-led information transmission studies. In our study 3, the transmission phase of the procedure, adapted from a previously published study (Vredenburgh et al., 2015), was enabled by an experimenter during a live interaction, rather than an experimenter-operated puppet, as in most studies of action transmission with older children who reached ToM milestone (Clegg & Legare, 2016; Corriveau et al., 2018; Ronfard et al., 2016). The experimenter presented herself as ignorant about the function of the novel toy and therefore explicitly prompted children to teach her what they know. This is in contrast to children's spontaneous information transmission in observational studies and diffusion chain paradigms (Whiten & Flynn, 2008, 2010). It is unclear, however, whether children perceived the transmission episode in our study as an opportunity to teach rather than to further explore the toys, whether they believed that the experimenter was genuinely not knowledgeable about the toy, and whether they perceived the social context as possibly inducing normativity in their choice of actions. It is an empirical

question which of these factors may have impacted the children's choice of actions, raising a general question about the level of detail with which infants interpret social contexts, social partners and subtle differences in phrasing. We further address some of these questions in the Limitations and Future Directions sections of this chapter.

IV.iii. Choice of outcome measures

We explored the relationships between multiple outcome measures (for a review, see LoBue et al., 2020) with the rationale that no measure on its own is inherently meaningful unless interpreted within the experimental context (Aslin, 2007; Bergmann et al., 2019; Sim & Xu, 2019). With this choice of measures in studies 1 and 2, we were able to demonstrate that preverbal infants' communicative and information seeking signals manifest through discrete social referencing looks. For example, previous research often used discrete number of social looks, accumulated looking time and duration of looks interchangeably, with studies reporting diverging results stemming from the different choice of measures (e.g., Brooker & Poulin-Dubois, 2013; Koenig & Echols, 2003; Vaish et al., 2011). Therefore, in study 1, we chose three social looking measures (frequency of social looks, latency to first look, and duration of looks) in order to disentangle the exact meaning of different types of attention and communication cues in epistemic uncertainty. The discrepancy in findings between these measures may index these as distinct measures underlying different cognitive mechanisms. Building on study 1, in study 2, we focused on measuring infants' discrete social looks (first looks and frequency of looks), while adding a complementary measure of the length of visual fixations as detected by the head-mounted eye-tracker.

As discussed in more detail in the Discussion Chapter section II.i, infants' looking at objects and at social partners may be subject to varying interpretations, as longer looking at the display of an object or physical event that violated infants'

expectations is traditionally interpreted as novelty response to the unexpected or impossible (Baillargeon, Spelke, & Wasserman, 1985; Stahl & Feigenson, 2015), while longer looking at a person, rather than an object, whose actions violated infants' expectations, may involve higher-order, communicative and intentional interpretations. At the same time, more research should be done to distinguish specifically between domain-general and domain-specific cognitive mechanisms in social interactive context, and the studies in the current thesis were not designed to resolve this long-standing debate. It must be noted in this regard that the previous literature on VoE in live, social interaction domain is very limited, warranting further research and measurement selection to enable comparisons between findings from object-induced and person-induced VoE studies.

While our choice of the main outcome measure in study 3 (first action) was consistent with the previously published paradigm (Vredenburgh et al., 2015), we included other measures, such as the frequency of both types of actions demonstrated and accidental discovery of non-demonstrated actions at the post-demonstration phase, and forfeited other previously used measures deemed unusable in light of the implemented manipulation changes, such as duration of actions and the switch and sequence analyses. While such rich datasets obtained from video recordings of social interaction studies undoubtedly provide ample coding opportunities, making a justified choice of measures remains the main methodological challenge in developmental science, which can be at least in part mitigated by adhering to transparency and open science principles (Gennetian, Tamis-LeMonda, & Frank, 2020; Frank, 2019).

Overall, the field is ripe for extending the existing and developing novel paradigms to assess early developmental mechanisms of active social learning and

knowledge transmission, with the current thesis offering useful recommendations for such designs.

IV.iv. General limitations

In addition to studies-specific methodological and theoretical considerations highlighted above, several broad limitations warrant further discussion. First, the sample characteristics of the participants (although this is based on anecdotal evidence because no demographic questionnaires were administered as part of the experimental studies) suggest that they came primarily from monolingual English-speaking, middle class population, referred to as WEIRD (wealthy, educated, industrialized, rich and democratic; Henrich, Heine, & Norenzayan, 2010). This limits the extent of the generalisability inferences that can be made from the current research. It may also have resulted in biased final samples submitted for analyses containing only the so-called 'good research babies': those who managed to maintain attention during the experimental procedure, whose caregivers volunteered them for participation in the first place and did not interfere with the procedure. Further, the sample sizes and the number of trials per participant in all three studies were relatively small, with an average attrition rate of 16% across all six experiments in this thesis (which is nevertheless in line with the 14% reported in infant looking-time studies, Slaughter & Suddendorf, 2007). Despite these limitations, the calculations of the effect size and the accompanying Bayes Factor analyses increase our confidence in the reported results. Future research should focus on replicating the findings from the current studies, expanding the sample characteristics and increasing the effect size through recruiting a larger sample or performing statistical analyses on the trial-level rather than participant-level basis. To mitigate these issues, future studies may also take advantage of the emerging large-scale

collaborative protocols (Byers-Heinlein et al., 2020) and online data collection efforts (Chouinard, Scott, & Cusack, 2019; Scott & Schulz, 2017).

In the studies reported in this thesis, we have not accounted for several individual factors, such as language, temperament, executive functioning, social cognition, and attachment, which may have affected infants' comprehension and performance on the social learning tasks. The exclusive reliance on verbal information in studies 1 and 2 may have limited some of the infants' understanding of the tasks and placed an unwarranted focus on variability in infants' verbal development. Infants' attachment to their caregivers may have also played a role in that infants with secure attachment may be more prone to learn from knowledgeable adults (as in study 2), while less securely attached infants may be unable to concentrate on forming the epistemic profiles of the experimenters and instead exclusively attend to their caregivers. The experimental procedures employed in this thesis were cognitively and socially intense as infants had to keep track of multiple people and objects. Having no immediate access to the novel and exciting toys in study 2 (during the opportunity to seek information phase of the test trials) may have been emotionally unsettling to some infants, thus interfering with their ability to engage in the epistemic appraisal of the situation. Differences in social development, including those which are characteristic of the autism spectrum disorder, may also impact social learning outcomes, such that while some children may effectively encode epistemic uncertainty, they still may not choose to ask social partners for help (as in study 2), or not show differentiation of information taught pedagogically and non-pedagogically (as in study 3). In light of these considerations, future research would benefit from obtaining data on individual differences to further probe the subtleties of social cognitive development.

While the experimental designs provided several crucial controls for a number of potential lower-level explanations of the effects, such as, in studies 2 and 3, the number of utterances and the order of speaking between the experimenters, several additional experimental controls would be beneficial. For instance, accounting for infants' inherent preferences to the objects or people, such as asking them "Which one do you like best?" rather than "Which one is the [pseudoword]?" (study 2) and "Can you show me how to play with it?" (study 3), could be one way to discriminate whether infants indeed selectively sought information from social partners (study 2) and attempted to teach them (study 3). Directly contrasting social and non-social, independent exploration phases in the same paradigm, with an interleaved design, would help mitigate this limitation. Additionally, we did not perform a pilot study to examine the intrinsic attractiveness or saliency of the objects (e.g., based on outcome sound, colour or shape) used in study 3, which may have affected toddlers' preferential choices. However, since the action complexity manipulation was operationalised as the tool-needed vs no tool-needed contrast, it is unlikely that lower-level properties played a major role.

V. Future directions

While the three research studies reported in the current thesis contribute to our understanding of behavioural manifestations of active social knowledge acquisition and transmission, the field is ripe for further investigation. Future work may benefit from extending the reported studies in several promising directions: the effect of active information seeking on decision making, learning and information transmission; exploring children's responses to various situations of epistemic uncertainty across different information modalities; and conducting longitudinal investigations to elucidate developmental change. The following section outlines the rationale for some of these proposals.

Future research should investigate preverbal infants' active information seeking when they would be motivated to not only acquire but to also peruse obtained information. Such paradigms could present infants with a situation where learning would be necessary to either obtain an interesting object, to make a behavioural choice, or to share what they learned with others. Previous research demonstrated that infants and older children retained information better if they selectively expressed their interest in it using pointing and explicit question asking as information seeking tools (Begus et al., 2014; Lucca & Wilbourn, 2018, 2019; see Lucca, 2020 for a review). However, it is unknown whether this effect is also present earlier in development, when, as suggested in this thesis, social referencing serves a proto-interrogative function. Furthermore, in light of the proposed connections between curiosity and teaching (van Schaik, Pradhan, & Tennie, 2019), future studies should investigate how active solicitation of information impacts its subsequent transmission, such as whether curiosity-driven motivation to obtain new knowledge makes such knowledge more likely to be shared.

Infants' active social learning across a variety of epistemic uncertainty situations is another promising avenue. For example, directly contrasting social (e.g., inaccurate labels) versus non-social (e.g., physical properties of objects) violations of expectation paradigms may help disentangle whether preverbal infants would prefer to seek information from social partners or instead engage in independent exploration. Along these lines, as discussed earlier, it would be important to further investigate social referencing in response to VoE scenarios that are social and non-social in nature, and in presence of one or more social partners, including those who are themselves a source of VoE (e.g., as a mislabelling adult) and those who are not. A variety of paradigms tapping into these issues would help to better understand the meaning of infants' responses, and especially their looks, which can be interpreted as surprise, confusion, attention, or communicative intention to seek social input.

To further elucidate infants' selective information seeking and information giving strategies, it would be beneficial to study how they resolve various complex situations of epistemic uncertainty, such as receiving conflicting, explicitly incompetent (deceitful or inaccurate), or misinformed (unintentionally wrong, e.g., when facing away from the object in question or being blindfolded) testimony, when informants may or may not override their initial incongruent testimony, or when the domain of knowledge is inconsistent with the informant's perceived expertise. Overall, future work with infants could shed light on early cognitive mechanisms underlying fact-checking and fact-finding: seeking expert opinions, corroborative evidence, verifying others' claims, and revising beliefs in face of new information (Butler, 2020; Koenig et al., 2004; Lane, 2018; Mills, 2013). The effects of these different knowledge acquisition parameters on transmission is also open for investigation, e.g., by asking under which epistemic conditions and what kind of information (e.g., surprising, contradictory,

confirmed by expert opinion, endorsed by majority, conforming to the norms, etc.) is more likely to spread widely (Corriveau et al., 2018).

The active child-led knowledge transmission field would progress by investigating whether spontaneous transmission emerges naturally; at what age children begin to transmit cultural information; what drives transmission, e.g., prosocial motivations, co-exploration, optimal learning and retention, or natural drive; what kind of information is likely to be transmitted, e.g., familiar or novel, surprising or mundane, opaque or transparent, general or specific, obtained independently or through pedagogical learning; who benefits from children's information transmission, e.g., social partners who are ignorant or knowledgeable, familiar or unfamiliar, reliable or unreliable, adults or peers, in-group or out-group members; and which social and emotional factors facilitate transmission. In addition to understanding the role of the learning context, future research should further elucidate the role of the type of information on transmission. In this thesis' study 3, both demonstrators provided easy to acquire, developmentally appropriate, rewarding, causally unambiguous, and undisputedly accurate information. Would young children preferentially transmit information learned in a pedagogical context following demonstration of causally opaque, inefficient or irrelevant information (e.g., Burdett, McGuigan, Harrison, & 2018; Corriveau, DiYanni, Clegg, Min, Chin, & Nasrini, 2017; Ronfard et al., 2016), socially conforming or more frequently endorsed (e.g., Morgan, Laland, & Harris, 2015), or information deemed socially acceptable or tabooed (e.g., Sheehagen, Schneider, Miebach, Frigge, & Zmyj, 2017)? These and other lines of research remain open to many exciting possibilities (Pasquinelli & Strauss, 2018).

Finally, understanding the dynamic changes in infants' active participation in social knowledge exchange as they mature is of utmost importance. The field is lacking

longitudinal studies of information seeking and transmission strategies as children navigate the increasingly complex social world (Grammer, Coffman, Ornstein, & Morrison, 2013). As documented in this thesis, early signs of interrogative communication and emerging teaching are present early, but these strategies inevitably become more complex and sophisticated with development. Longitudinal study designs would allow to track communicative tools used for information seeking and information giving at different stages of development and across different types of epistemic testimony, informant's characteristics, and information modalities. For example, future research could ask whether older children continue to use social referencing in the same manner as preverbal infants, or if they 'grow out of it' in favour of other strategies, such as pointing, with social referencing eventually losing its function as an interrogative tool (but see Hechenbaher et al., 2017, 2020, for social referencing in preschool aged children). While this thesis deliberately focused on the youngest populations to elucidate the earliest manifestations of information seeking and its transmission, future research would greatly benefit from longitudinal paradigms to track the developmental change in these cognitive abilities.

VI. Conclusion

The current thesis contributes to our understanding of the cognitive mechanisms of active learning and active teaching as manifested in early development among 11-24-month-olds. Experimental Chapters 1 and 2 were dedicated to the early developing active communicative and information seeking behaviours that preverbal infants use when facing epistemic uncertainty in a social context. Infants showed sensitivity to knowledge distribution among social partners, to their reliability and accuracy in information provision, and exhibited active social behaviours to help resolve epistemic uncertainty. Importantly, these studies underline the function of social referencing as communicative and information seeking, emerging prior to interrogative pointing, and occurring specifically in epistemic rather than the previously highlighted emotional or cognitive-perceptual uncertainty. Experimental Chapter 3 demonstrated infants' early developing propensity to transmit knowledge to social partners who are less knowledgeable. Toddlers showed propensity for information transmission and ability to adjudicate what information to transmit preferentially as a function of its social and non-social properties. Furthermore, this study revealed the limits of the theories postulating the privileged role of pedagogy in cultural knowledge transmission by providing evidence for preferential transmission of less complex actions, but no evidence for preferential transmission of pedagogically communicated actions. Overall, the thesis makes a methodological contribution by highlighting the importance of live social interaction experimental paradigms in developmental research on cultural information transmission and a theoretical contribution by elucidating active behavioural manifestations of information seeking and information giving in infancy.

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