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Knowing who knows: Metacognitive and causal learning abilities guide infants' selective social learning

Olivia Kuzyk | Shawna Grossman | Diane Poulin-Dubois

Concordia University, Montréal, Québec, Canada

Correspondence
Olivia Kuzyk, Centre for Research in Human Development, Department of Psychology, Concordia University, 7141 Sherbrooke Street West, Montréal, Québec, H4B 1R6, Canada.
Email: olivia.kuzyk@gmail.com

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Abstract
Given the widespread interest in the development of children's selective social learning, there is mounting evidence suggesting that infants prefer to learn from competent informants (Poulin-Dubois & Brosseau-Liard, *Current Directions in Psychological Science*, 2016, 25). However, little research has been dedicated to understanding how this selectivity develops. The present study investigated whether causal learning and precursor metacognitive abilities govern discriminant learning in a classic word-learning paradigm. Infants were exposed to a speaker who accurately (reliable condition) or inaccurately (unreliable condition) labeled familiar objects and were subsequently tested on their ability to learn a novel word from the informant. The predictive power of causal learning skills and precursor metacognition (as measured through decision confidence) on infants' word learning was examined across both reliable and unreliable conditions. Results suggest that infants are more inclined to accept an unreliable speaker's testimony on a word learning task when they also lack confidence in their own knowledge on a task measuring their metacognitive ability. Additionally, when uncertain, infants draw on causal learning abilities to better learn the association between a label and a novel toy. This study is the first to shed light on the role of causal learning and precursor metacognitive judgments in infants' abilities to engage in selective trust.

KEYWORDS
causal learning, decision confidence, metacognition, selective trust

1 | INTRODUCTION

Children frequently learn from those around them as they explore and interact with their social world. Through observing and imitating others, children acquire many learned skills that would otherwise be difficult—if not, impossible—to develop on their own. As such, socially learned behavior (e.g. tool use, language and cultural norms) is a critical feature of child development (Wood et al., 2016). However, social information can be outdated and inappropriate. Children must be able to filter among potential informants and keep track of those who can offer accurate information in order to successfully learn from those around them. A plethora of research has demonstrated that children actively engage in social learning strategies that enable them to differentiate between reliable and unreliable sources of information, and then display selective trust in one source over another (Koenig & Harris, 2005; Koenig & Sabbagh, 2013; Mills, 2013; Nurmsoo, Robinson, & Butterfill, 2010). To date, a large body of evidence has revealed that even infants are sensitive to several properties of a social model to guide their learning. For example, it has been shown that infants are attuned to informants' accuracy (e.g. Brooker & Poulin Dubois, 2013), age (e.g. Ryalls, Gul, & Ryalls, 2000), and confidence (e.g. Brosseau-Liard & Poulin-Dubois, 2014) to help them decide from whom to learn.

Despite growing empirical support for children's selectivity in social learning, there is surprisingly little research dedicated to understanding how this selectivity develops (Heyes, 2016a). There is considerable theoretical disagreement among researchers over the mechanisms underlying selective social learning in early childhood and infancy. Consistent with a rich account of early selective trust, researchers argue that social learning in young children is governed by domain-specific, higher-order, cognitive abilities (e.g. Poulin-Dubois, 2017). In contrast, a lean perspective holds the view that young children rely on domain-general, lower-order, cognitive functions (Heyes, 2016b). According to the latter account, the abilities that underlie selective social learning in infancy are unsophisticated and shared with non-human animals, namely associative processes. Indeed, experimental studies have revealed functional parallels in social learning across human and non-human animals (Rendell et al., 2011 for a review). For example, like humans, a fresh water fish species has been shown to copy others when uncertain (van Bergen, Coolen, & Laland, 2004). Research with chimpanzees shows a preference to copy individuals of higher rank and prestige (Horner, Proctor, Bonnie, Whiten, & de Waal, 2010). This literature shows us that even animals use state-based (e.g. copy when uncertain) and model-based (e.g. dominance rank based) social learning strategies to acquire important information for their survival (Rendell et al., 2011).

Some attention has been given to the psychological mechanisms mediating the selectivity of this behavior in non-human animals. The mechanisms proposed are domain-general processes based on principles of associative learning—those that are driven by the learned predictiveness of a stimulus. Broadly, the predictiveness of a stimulus refers to the accuracy of predicting action-outcome relations (Le Pelley, Vadillo, & Luque, 2013). Research indicates that learning of action-outcome relations occurs more readily when the stimulus consistently elicits the same outcome (Le Pelley et al., 2013). More attention is directed to predictive stimuli relative to non-predictive stimuli, which therefore increases the rate by which an association is learned (Le Pelley et al., 2013). The ability to learn about relations and predict future behavior is also thought to be based on causal theories of learning (Sawa, 2009). Causal learning refers to the ability of inferring causal relations from patterns of observed events and their respective outcomes (Gopnik et al., 2004). Specifically, we form internal causal models by observing sequences external of events that are temporally contingent (Sawa, 2009).

It has been suggested that similar, basic mechanisms operate in human social learning—particularly early in life. Heyes (2016a) suggests that evidence of early selective social learning is often interpreted in a way that implies that children's behavior is guided by conscious efforts to apply learning strategies. Instead, children's learning may be driven by associative processes (Heyes, 2016a). To illustrate, in a study by Brooker and Poulin-Dubois (2013), infants demonstrated a preference to learn a new word from a reliable informant (i.e. who labelled familiar objects correctly) relative to an unreliable informant (i.e. who labelled familiar objects incorrectly).

Research Highlights

- This is the first evidence of the predictive power of both causal learning and precursor metacognitive abilities on infants' selective social learning.
- 18-month-old infants appear to be more inclined to learn from an unreliable informant when they lack confidence in their own knowledge.
- Infants may draw on causal reasoning abilities to learn the association between a label and a novel object.

From an associative perspective, infants were less likely to learn from an unreliable informant because the association between the label and the familiar object was not predictive. The unreliable informant provided a label that did not accurately predict the object that was presented. This led the infants to attend less and learn less from the speaker. More sophisticated abilities are proposed to come online in late childhood and play a larger role in adulthood due to social experience (Heyes, 2016b).

Alternatively, other researchers maintain that individual differences in precursor domain-specific abilities may explain early selective social learning (Harris & Koenig, 2006; Poulin-Dubois, 2017; Sabbagh, Koenig, & Kulmeier, 2017; Sobel & Kushnir, 2013). In particular, theory-of-mind (ToM), or the ability to make rational inferences about others' mental states has been proposed to account for this link. Evidence in preschoolers suggests that children are capable of attributing knowledge or ignorance based on the accuracy or inaccuracy of an informant's behavior. These mental state inferences are thought to guide children's decisions about whether to endorse one informant relative to another (Brosseau-Liard, Penney, & Poulin-Dubois, 2015; Harris & Koenig, 2006; Sobel & Kushnir, 2013). Therefore, it is proposed that children who demonstrate a stronger understanding of others' mental states would also be more successful selective social learners (Brosseau-Liard et al., 2015; Sobel & Kushnir, 2013). This has been demonstrated in children of pre-school and school age (Brosseau-Liard et al., 2015; DiYanni, Nini, Rheel, & Livelli, 2012; Elashi & Mills, 2014; Lucas, Lewis, Pala, Wong, & Berridge, 2013). However, other studies have yielded inconsistent results, in that young children's ToM abilities have no bearing on the selectivity of their learning (e.g. Pasquini, Corriveau, Koenig, & Harris, 2007). Additional research is required to further elucidate the relation between these abilities.

To our knowledge, there are two studies that sought to examine whether domain-specific or domain-general abilities govern selective social learning in infants. Crivello, Phillips, and Poulin-Dubois (2017) reported that 18-month-old infants who were able to correctly make inferences about the knowledge state of others were less likely to accept an unreliable informant's testimony. More specifically, infants who correctly inferred the knowledge state of an experimenter, also demonstrated decreased willingness to learn a novel word from an informant who had previously displayed incompetence. No association was observed with statistical learning abilities, suggesting that infants' abilities to extract statistical regularities from their environment was not associated with their selective word learning abilities. In a recent follow-up study, Crivello, Lazo, and Poulin-Dubois (2019) examined the extent to which knowledge inference and associative learning abilities guide 14-month-old infants' detection of emotional incongruence (i.e. display of happiness while looking at an empty container). Consistent with previous results, infants who demonstrated stronger abilities to make inferences about others' knowledge states were better able to detect the unreliability of an emoter. Again, no link with associative learning was revealed. Together, these studies provide evidence for a domain-specific account of early selective trust.

Many would argue that that ToM and metacognitive abilities are synonymous, such that both concepts refer to knowledge of mental states (Flavell, 2000). Despite this obvious similarity, operational definitions of these constructs differ (Ebert, 2015).Here, we refer to ToM abilities as an understanding of *other's* mental states such as beliefs, intentions, as well as desires (Wellman, 2014), and refer to metacognition as the ability to reflect on *one's own* thinking and learning (Flavell, 1979; Geurten & Willems, 2016). That said, metacognitive abilities have also been proposed to govern selective social learning (Heyes, 2016b). Heyes (2016b) argues that explicit metacognitive social learning strategies permit the creation of social traditions and the transmission of wisdom. Explicit metacognition enables successful learning, such that individuals adjust their learning strategies based on their state of knowledge. Humans apply social learning strategies in more sophisticated ways that reflect their possible metacognitive content and direct their learning to better sources of information. For instance, the “copy the majority” social rule becomes “copy the majority when the majority is likely to know best” (Heyes, 2016b). A body of work with adults demonstrates that learning strategies that specify when and from whom to learn can be metacognitive in nature. For example, adults are more likely to use social information to respond to ambiguous perceptual and foraging tasks when their explicit confidence judgments were lower (Morgan, Rendell, Ehn, Hoppitt, & Laland, 2012).

Extant research supports that explicit metacognitive ability is predictive of successful social learning strategies even in school-age children (e.g. Dunlosky & Rawson, 2012; Sodian & Frith, 2008). However, young children under the age of four years have been shown to make inaccurate metacognitive judgments (e.g. Flavell, 1999; Sodian, Thoermer, Kristen, & Perst, 2012). Researchers suggest that young children's explicit metacognitive abilities are underestimated in these studies given that the measures rely heavily on verbal ability. When non-verbal measures are considered, it appears that these abilities may emerge earlier than expected (Goupil & Kouider, 2016; Goupil, Romand-Monnier & Kouider, 2016 ; Paulus, Proust, & Sodian, 2013). For instance, similar electrophysiological signatures of error monitoring are elicited in adults and infants following an incorrect decision (Goupil et al., 2016). In addition, pupillometric analysis in preschoolers reveals evidence for implicit metacognitive memory monitoring (Paulus et al., 2013). Behavioral forms of metacognition are assessed using decision confidence monitoring and information-seeking paradigms—those that involve observing infants' behavior under conditions that create uncertainty following a memory manipulation.

For example, it appears that 20-month-old infants are capable of monitoring and expressing their uncertainty to others ((Goupil, Romand-Monnier, & Kouider, 2016). When asked to retrieve a toy from one of two boxes following a delay, infants more frequently seek help from a caregiver when required to decide between the two boxes themselves. Thus, when given the opportunity to ask for help, infants selectively use this strategy to avoid making errors. Using a similar paradigm, Goupil and Kouider (2016) suggest that 18-month-old infants also monitor the accuracy of their decisions. Following a delay of several seconds, infants were asked to identify which of two identical boxes contained a toy, and were prompted to search the box that they selected. Interestingly, infants displayed increased post-decision persistence (i.e. duration of searching the box) for correct choices as compared to incorrect choices. These studies suggest that infants possess abilities related to error monitoring and developing estimates of decision confidence that guide their behavior.

The main objective of the present research was to investigate whether causal learning and precursor metacognitive abilities can account for 18-month-old infants' ability to avoid learning from incompetent informants. Infants were presented with a speaker who either accurately or inaccurately labeled a familiar object. Following this event, infants' willingness to learn a novel word from the speaker was examined. Based on prior findings using the word-learning paradigm, it was expected that infants would be less likely to learn a novel word from an unreliable speaker relative to a reliable one (Brooker & Poulin-Dubois, 2013; Koenig, Clément, & Harris, 2004; Luchkina, Sobel, & Morgan, 2018). Consistent with extant research on the mechanisms of early selective trust (Crivello et al., 2017, 2019), it is hypothesized that selective social learning in infancy is governed by domain-specific abilities. More specifically, infants with better awareness of their confidence—as measured through a decision confidence paradigm—will be less likely to display selective trust in an unreliable source. Performance on a causal learning task is not hypothesized to predict infants' selective word-learning. This prediction is based on previous studies that have not reported a link between domain-general skills and selective trust abilities. Finally, infants' performance on both correlate tasks is not expected to predict word-learning from a reliable informant, given that infants have been shown to learn new words from a model without any information about their competence.

2 | METHOD

2.1 | Participants

Participants lived in a large metropolitan Canadian city and were recruited from birthlists provided by a governmental health agency. A total of 92 infants, aged 18 months, were tested. Selection criteria required that children did not have auditory or visual impairments, or any birth complications. Importantly, inclusion criteria required that infants be exposed to English or French. Given that the word-learning task served as the basis for the study, the following exclusions are specific to the word-learning task. An additional 28 infants were excluded as a result of fussiness (*n* = 10), having a dominant language that was not English or French (*n* = 12), providing ambiguous responses such as offering both toys or none (*n* = 4), parental interference (*n* = 1), and experimenter error (*n* = 1). Thus, the final sample consisted of 64 infants (M_{age} = 18.20 months, *SD* = 0.99, range = 16–20.30 months; 31 males, 33 females).

2.2 | Procedure

2.2.1 | MacArthur-based short form vocabulary checklist: level II (MCDI-II)

American-English and French-Canadian adaptations of the MCDI were administered to assess infants' total productive vocabulary (Fenson et al., 2000; Trudeau, Frank, & Poulin-Dubois, 1999). The MCDI-II, developed for children between the ages of 16 and 30 months, is comprised of 100 items. The child's primary caregiver completed the form.

2.2.2 | Word comprehension checklist

French and English versions of a 20-word checklist were administered to obtain a brief estimate of children's receptive vocabulary, and to select words for the word-learning task (Brooker & Poulin-Dubois, 2013). The form was used to select stimuli for the task.

2.2.3 | Selective word-learning task

In a procedure identical to that of Brooker and Poulin-Dubois (2013), and Crivello et al. (2017), infants were presented with labels for familiar and novel stimuli.

Reliability exposure phase

Participants were allocated to a reliable (*n* = 33) or unreliable (*n* = 31) condition through random assignment. A total of four small plastic toys were selected based on the words endorsed by the child's caregiver on the 20-word checklist and were either labelled correctly (reliable) or incorrectly (unreliable). Participants were required to be familiar with a minimum of three of the four words in order to be included for analysis (Brooker & Poulin Dubois, 2013; Crivello et al., 2017). First, children were given 15 s to explore each of the toys. Following this, the experimenter labeled each object with the same label three times. The child was given the toy again to play with (15 s) immediately after labelled by the experimenter.

Word-learning phase

The word-learning phase assessed children's willingness to learn from the informant. This was comprised of three sub-phases: warm-up, training, and test phase. First, the experimenter presented the child with two other familiar toys on a tray and requested one from the child. In the training phase, the experimenter introduced two novel toys, and modeled how to play with each of the toys. Children were then given 15 s to explore both toys. The experimenter then retrieved one of the toys from the child and labelled it a "Dax." The experimenter provided this label a total of four times. The test phase consisted of two trial types: familiar and novel trials, wherein a pair of familiar and novel toys were introduced. The familiar toys were different from those shown in previous trials, and the novel toys were the same as those described above. The same pair of novel toys was presented to the child across all novel trials. A total of 8 trials were administered (four familiar and four novel) alternating in order. On each trial, the experimenter requested one of the two objects (i.e. "Where is the X? Give me the X"). Importantly, on the novel trials, the experimenter only requested the novel toy she had previously labeled as the "Dax." If the child offered two toys simultaneously, then the trial was repeated. The type of trial and novel toy as well as the location of the toys on the tray were all counterbalanced. The number of correct responses on test trials were coded for a maximum score of 4 across trial type.

2.2.4 | Causal learning task

An adaptation of the blicket task was administered to measure early causal learning abilities (Sobel & Kirkham, 2006). A blicket detector was used—identical to that described by Sobel and Kirkham (2006). The detector became activated when an object was placed on the red top and was deactivated when the object was removed. When activated, the detector lit up and played a song. A total of nine blocks—different in shape and color—were used as stimuli. The detector and the blocks rested on a tray throughout the administration.

First, the imitation trial required that the experimenter place two blocks on opposite ends of the tray, and then place each block separately on the detector. Only one of the blocks activated the detector. This was demonstrated twice. The experimenter provided verbal cues when one block activated the detector, and when the other did not by saying "Wow" or "No." The experimenter encouraged the child to activate the detector by sliding the tray over and saying "It's your turn. Make it go." The child was only given one opportunity to make a response.

A total of three experimental trials were administered. The location of the blocks on the tray for each trial was counterbalanced. On the first trial, two different blocks were successively placed on the tray (A and B). Block A activated the detector, whereas Block B did not. Then, both blocks were placed on the detector, and it was activated. This was demonstrated twice. Following this, the experimenter slid the tray over to the child and said "It's your turn. Make it go." Next, another pair of blocks was placed on the tray. Both blocks were placed on the detector twice, activating the machine. Then, one of the two blocks (Block B) was placed on the detector, and the machine did not activate. The experimenter subsequently slid the tray over to the child and said “It's your turn. Make it go.”

Finally, three different blocks were placed on the tray. Two blocks (A and B) were placed on either end of the tray, and the third (C) was placed in the middle. Blocks A and C were placed on the detector together twice, which activated the detector both times. Only Block C was placed on the detector, and the machine activated. Block C was then removed, and the tray was slid over to the child while the experimenter said “It's your turn. Make it go.” The proportion of correct test trials was calculated.

2.2.5 | Metacognition task

Adapted from the task designed by Goupil and Kouider (2016), an interactive metacognitive task was used to measure infants' ability to monitor decision confidence. Infants were exposed to two identical black boxes that were akin to the original experiment. The boxes were designed so that children were able to reach inside the boxes, but unable to see its contents. Inside each of the boxes, a small pocket was hidden. The stimuli used for the warm-up and familiarization trials were small plastic toys. The test stimuli consisted of four colorful rectangular wooden blocks. The stimuli were randomly selected for each trial. Finally, a small puppet theatre was used with two black curtains hanging from it.

First, the experimenter introduced each of the boxes by saying “Look [child's name]! The nice box! I put my hand inside! You try!” The experimenter pushed the box towards the child so that it was within his/her reach, encouraging the child to put his/her hand inside the box. A total of two warm-up trials were administered, wherein a toy was hidden in one of the two boxes and infants were asked to retrieve the toy. Before hiding the toy, the experimenter presented it to the child by centering it on the table and saying “Look [child's name]! A toy! I hide it in the box!” After the child watched the experimenter place the toy in the box, it was pushed forward so that the child can retrieve the toy.

Two familiarization trials were then administered. Similar to the warm-up trials, the familiarization trials followed the procedure outlined above. However, the familiarization trials required both boxes to be pushed toward the child so that he/she was required to select the box that he/she thought the toy was hidden. As the experimenter pushed the boxes forward, she said, “Where is the toy? Can you show me?” The experimenter waited until the child pointed to one of the boxes, and then moved the box forward. Correct responses were praised, whereas incorrect responses were corrected. If the child selected the incorrect box, he or she was given the opportunity to search the correct box for the toy. A total of eight experimental trials were then administered. The procedure was identical to that of the familiarization trials, except that the experimental trials incurred a delay (6 or 9 s randomized in order), and both boxes were hidden from the child's view by a curtain. Importantly, the toy was now secretly hidden in a pocket inside the box, rendering the toy impossible for the child to find. Post-decision persistence time (s) was measured by coding the amount of time the child searched the box.

2.3 | Design

Prior to the testing session, infants were exposed to a warm-up phase in order to become accustomed to the environment and the experimenters. During this period, the caregiver was asked to complete the MCDI-II and the Word Comprehension Checklist. Infants were randomly assigned to either the reliable or unreliable condition, and the administration of the word-learning task followed. Counterbalanced in order, the causal learning and metacognition tasks were then administered. The word-learning task was always administered first given that performance on this task was critical for our main analysis, and thus made it important to circumvent fatigue effects. The experimenter who administered the word-learning task did not administer either of the subsequent tasks in order to avoid possible carry-over effects. Parents were offered $20 to cover travel costs, and children were given a small toy and a certificate of merit.

3 | RESULTS

A series of comparative analyses were conducted across the reliable and unreliable conditions of the selective word-learning task to ensure that the groups were equivalent in age, gender, and vocabulary knowledge. Analyses revealed no significant differences in age t (64) = 0.25, p = .80, d = 0.04, or gender, χ^2 = 0.06, p = .81. More importantly, analyses did not yield significant differences in the proportion of known words on the Word Comprehension Checklist (index of receptive vocabulary), t (64) = 0.92, p = .36, d = 0.04 or on the MCDI-II (index of expressive vocabulary), t (64) = −.25, p = .81, d = 0.07. Finally, participants did not differ on the proportion of words they were familiar with on the 20-word checklist used for the reliability phase of the word-learning task, t (64) = −0.14, p = .89.

3.1 | Selective word-learning task

To examine possible fatigue effects, a one-way analysis of variance was conducted across 8 trials, irrespective of condition and trial type, with correct choice as the dependent variable.

The analysis revealed a significant decrease in the number of correct offers across trials, F (1, 452) = 13.23, p < .001, η^2 = 0.39. Two binary logistic regression models were conducted to assess whether correct responses on the task varied as a function of block (first four vs. last four trials) and trial type (familiar vs. novel trials) across unreliable and reliable conditions. Both predictors were entered into the models simultaneously. The model conducted for the unreliable condition yielded significant findings, χ^2 (2) = 9.10, p = .01, Nagelkerke

R^2 = 0.055. Trial type significantly predicted correct offers of the target object irrespective of block (b = 0.77), such that infants were 2.2 times more likely to offer the target object across familiar trials relative to novel trials. The model for the reliable condition also yielded significance, χ^2 (2) = 6.01, p = .05, Nagelkerke R^2 = 0.035. Block of trials significantly predicted correct responses, irrespective of trial type (b = 0.59). Infants in the reliable condition were 1.8 times more likely to offer the target object in Block 1 relative to Block 2. Given these results, subsequent analyses for the selective word-learning task only included the first four trials (two novel and two familiar) to minimize statistical error in the data.

A mixed analysis of variance was conducted in order to examine differences in performance across both conditions on familiar and novel trials. The proportion of correct responses was entered as the dependent variable. A significant main effect of trial type emerged, wherein infants' performance on familiar trials (M = 0.71, SD = 0.38) was superior as compared to performance on novel trials (M = 0.56, SD = 0.33), F (1,62) = 4.80, p = .03, η^2 = 0.07. Additionally, a significant main effect of condition was observed, in that infants in the reliable condition correctly offered the target object more frequently irrespective of trial type (M = 0.72, SD = 0.33), relative to the unreliable condition (M = 0.56, SD = 0.33), F (1,62) = 7.46, p = .01, η^2 = 0.107). A Condition x Trial type interaction emerged as a trend, F (1,62) = 3.44, p = .07, η^2 = 0.05. Consistent with our hypotheses, planned comparisons revealed that infants in the reliable condition presented with a larger proportion of correct offers on novel trials (M = 0.71, SD = 0.37) relative to infants in the unreliable condition (M = 0.42, SD = 0.38), F (1,62) = 7.93, p = .01, η^2 = 0.11). Also in line with our predictions, differences between reliable and unreliable conditions across familiar trials were not observed, F (1, 62) = 0.06, p = .81, η^2 = 0.001 (see Figure 1). Proportion of correct offers across familiar and novel trials were subsequently examined against chance responding (0.50). On familiar trials, infants in both the reliable (M = 0.73, SD = 0.36), t (32) = 0.37, p = .001, and unreliable condition

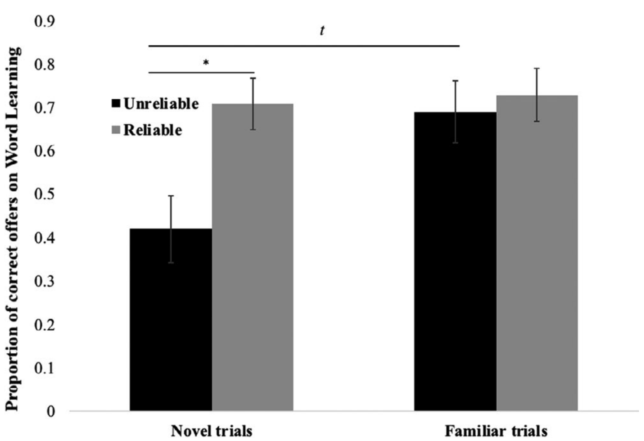

FIGURE 1 Performance on the selective word learning task across unreliable and reliable conditions. Error bars represent standard error of the mean. *Significantly different performance in unreliable and reliable groups on novel trials. [t] trend difference between novel and familiar trials in unreliable group

(M = 0.69, SD = 0.40), t (30) = 2.68, p = .01, performed above chance. On novel trials, infants in the reliable condition performed above chance (M = 0.71, SD = 0.35), t (32) = 3.35, p = .002 whereas infants in the unreliable condition did not differ from chance level (M = 0.42, SD = 0.32), t (30) = −1.41, p = .17.

3.2 | Correlates of selective social learning

Children's performance on each of the correlate tasks was first examined, regardless if they were included on the selective word-learning task. This was in order to evaluate children's performance relative to performance reported in the original studies.

3.2.1 | Causal learning task

Performance on the Blicket task was examined relative to a chance criterion (0.50) to reflect two possible response options across trials. Akin to Sobel and Kirkham (2006), only infants who passed the imitation trial were included in the analysis. Of the 92 participants who were tested, analyses were conducted among a sample of 56 infants. A total of 36 participants were excluded—specifically, because of failure of the imitation trial (n = 18), fussiness (n = 11) or technical difficulties (n = 7). Although slightly higher than the attrition rate reported in the original study (Sobel & Kirkham, 2006), this attrition rate is typical for studies that include more than one task. Results revealed that performance on both the "screening-off trial" and the "indirect screening-off trial" did not differ from chance, such that 42% (p = .40) and 56% (p = .50) of infants placed the correct block on the detector, respectively. Similarly, performance on the backward blocking trial was at chance level (64%; p = .16). Consistent with the original study, chance responding was compared to the frequency with which infants placed block A on the detector given the ambiguity of the correct response.

Given that trials were presented in a fixed order, subsequent analyses were conducted to test for order effects. Results indicated that performance on the "screening-off trial" influenced performance on the "indirect screening off trial," χ^2 (1, N = 56) = 36.64, p = .002, and "backward blocking trial," χ^2 (1, N = 56) = 36.64, p = .002. Additionally, the impact of performance on the "indirect screening trial" on performance on the "backward blocking trial" emerged as a trend, χ^2 (1, N = 56) = 12.98, p = .07. Results suggest that performance on later trials was influenced by performance on trials that were previously administered.

3.2.2 | Metacognition task

Analysis for the metacognition task was conducted among a sample of 61 infants. A total of 31 participants were excluded—specifically, due to fussiness (n = 17), non-responsiveness across trials (n = 6), not having completed a sufficient number of trials (n = 5), side preference (n = 2) and experimenter error (n = 1).

A one-way analysis of variance was first conducted to examine possible fatigue effects across the 8 trials, irrespective of delay (6 or 9 s). The dependent variable was infants' accuracy in identifying the box where the toy is hidden. Results indicated a significant decrease in accuracy across trials, F (1, 420) = 11.43, p = .001, η^2 = 0.31. A binary logistic regression was subsequently conducted to assess whether accuracy on the metacognition task varied across block (first four vs. last four trials) and memorization delay (6 vs. 9 s). The model yielded significant findings, χ^2 (2) = 8.80, p = .01, Nagelkerke R^2 = 0.03. Block of trials emerged as a significant predictor of accuracy (b = 0.60), whereas memorization delay did not (b = −0.01). Results suggest that infants were 1.8 times more likely to respond correctly across trials in Block 1 relative to trials in Block 2 and were equally likely to accurately identify where the toy was hidden across trials with 6- and 9-s delays. Given these findings, subsequent analyses for this task included the first four trials in an effort to reduce the amount of statistical error in the data.

Following this, a paired-samples comparison was conducted to evaluate differences in persistence time (s) across correct and incorrect trials. Infants were not included in this analysis if they achieved perfect accuracy across all four trials. Of note, data screening revealed that persistence time data were not normally distributed and were thus log transformed. Results from paired-samples comparisons with log transformed values and original data were compared and were found to yield similar findings. Thus, non-transformed data are reported in an effort to preserve the original metric and facilitate the interpretation of results. Descriptive statistics indicated that, on average, infants correctly identified the location of the toy across 2.31 trials (SD = 0.73) and incorrectly identified the location of the toy across 1.60 trials (SD = 0.69). Consistent with our predictions and in line with those of the original experiment (Goupil et al., 2016), infants demonstrated increased persistence on correct trials (M = 2.87, SD = 1.21) relative to incorrect trials (M = 2.07, SD = 1.01), t (53) = 5.72, p = .001, d = 0.72. Moreover, a positive correlation emerged between persistence time on correct and incorrect trials, r (60) = 0.470, p = .002.

3.3 | Inter-task relations among word-learning and correlate tasks

Inclusion criteria required that infants completed all three tasks in order to be included in regression analyses. For the causal learning task, infants were included for analysis irrespective of whether they passed (n = 37) or failed (n = 8) the imitation trial to maximize sample size. As such, a proportion score out of 4 trials was analyzed (M = 0.60, SD = 0.22, range = 0.25–1). The final sample consisted of 41 infants (Unreliable: n = 21; Reliable: n = 20). Zero-order correlations were conducted in order to examine the associations between performance on novel trials of the learning task and performance on the correlate tasks in the reliable and unreliable conditions independently. Bootstrapping procedures were followed given that they are recommended practice when data violate normality assumptions and for analyses with small sample sizes (Dwivedi, Mallawaarachchi, & Alvarado, 2017). Analyses yielded no significant correlations among the selective social learning task and correlate tasks in the reliable condition. A positive association was obtained between infants' scores on the causal learning task and performance on novel trials of the selective social learning task in the unreliable condition, r (20) = 0.52, p = .02, 95% CI [0.109, 0.776]. A negative relation emerged between persistence time on incorrect trials of the metacognition task and performance on novel trials in the unreliable condition, r (20) = −0.43, p = .05, 95% CI [−0.737, −0.007]. Zero-order correlations among the selective-word learning task and correlate tasks are displayed in Table 1.

3.4 | Regression models predicting performance on novel trials of word-learning task

A series of hierarchical regression models were conducted in order to derive estimates of the predictive power of each of the correlate tasks on performance on novel trials of the selective word-learning task across both reliable and unreliable conditions. Given that zero-order correlations among performance on novels trials of the word-learning task and post-decision persistence on correct trials of the metacognition task did not yield significance, infants' persistence on incorrect trials were only included in regression models. To examine the predictive power of metacognitive ability

TABLE 1 Zero-Order correlations among Selective Word-Learning task and Correlate tasks

Variables	1	2	3	4	5
Unreliable (n = 21)					
Causal learning task	...	0.14 p = .56	−0.12 p = .60	0.005 p = .98	0.52* p = .02
MC PT correct trials		...	0.42^t p = .06	0.10 p = .67	−0.01 p = .97
MC PT incorrect trials			...	0.05 p = .82	−0.43* p = .05
Accuracy on MC task				...	0.13 p = .59
SWL task (unreliable)					...
Reliable (n = 20)					
Causal learning task	...	0.17 p = .48	−0.11 p = .64	0.09 p = .71	0.15 p = .53
MC PT correct trials		...	0.51* p = .02	0.28 p = .24	0.09 p = .70
MC PT incorrect trials			...	−0.11 p = .66	−0.18 p = .45
Accuracy on MC task				...	0.65** p = .002
SWL task (unreliable)					...

Note: Bootstrapping procedures were used to derive more accurate estimates of zero-order correlation coefficients.
MC, metacognition task; PT, persistence time; SWL, selective Word-Learning; ^{t}refers to statistical trend.
*Refers to significance at p < .05 level;
**refers to significance at <0.001 level.

above and beyond that of causal learning, performance on the causal learning task was entered first, followed by persistence time on incorrect trials of the metacognitive task. Performance on novel trials was included as the criterion. Robust regression parameters were estimated using bootstrapping procedures described by Dwivedi et al. (2017).

3.4.1 | Model 1: Predicting performance on novel trials in the unreliable condition

In step 1, causal learning predicted scores, and accounted for approximately 27% of the variance on novel trials, F (1, 19) = 6.99, p = .016, R^2 = 0.27. When metacognitive ability was entered into the model, both predictors of interest significantly predicted scores on novel trials, ΔF (2, 18) = 6.23, p = .009, R^2 = 0.41. The change in R^2 value indicated that an additional 14% of variance was explained by persistence time on incorrect trials of the metacognition task, ΔR^2 = 0.14. Given these values, it can be interpreted that a significant portion of the variance in scores on novel trials was explained by the predictor variables, and that both predictor variables contribute significantly to the variance explained in the model. Values displayed in Table 2 correspond to the unstandardized regression coefficients, standard errors of the mean, beta weights, R^2 values, t values, and respective significance values. For the final regression model, the lower and upper limits of the 95% confidence interval for causal learning were 0.24 and 1.13, whereas upper and lower limits for metacognitive ability were −0.22 and −0.01. Because confidence intervals did not span zero, these results indicate that greater proportion of correct trials on the causal learning task is associated with a larger proportion of correct novel trials on the selective social learning task (β = 0.47, t (20) = 2.59, p = .02). Moreover, results suggest that a decrease in persistence time values on incorrect trials of the metacognition task is associated with more willingness to learn from the incompetent speaker as reflected in a larger proportion of correct novel trials (β = −0.38, t (20) = −2.10, p = .04).

3.4.2 | Model 2: Predicting performance on novel trials in the reliable condition

Performance on novel trials of the selective word-learning task was not significantly predicted by the predictor variables of interest at Step 1 and 2, ΔF (2, 17) = 0.43, p = .66. The unstandardized regression coefficients, standard errors of the mean, beta weights, R^2 values, t values, and respective significance values are presented in Table 3. In other words, the predictor variables did not account for a meaningful portion of variance on novel trials of the selective word-learning task.

4 | DISCUSSION

The present study addressed two important questions in the field of early selective trust: (a) whether causal learning and precursors of metacognitive abilities support selective social learning in 18-month-olds, and (b) to what extent does each of these abilities predict such discriminant learning in infants. There is a considerable amount of disagreement surrounding the psychological underpinnings at the origins of selective social learning. According to one account, infants draw on domain-general cognitive abilities (Heyes, 2016a), whereas another account posits that young children use higher-order, domain-specific cognitive mechanisms to resist learning from an unreliable speaker (Poulin-Dubois & Brosseau-Liard, 2016; Sabbagh et al., 2017). To our knowledge, this is the first investigation of causal learning and precursor metacognitive abilities as potential mechanisms associated with selective social learning in infancy. This study presents evidence of predictive relations between both causal learning and metacognitive abilities with epistemic trust in infancy.

The classic selective word-learning paradigm was adapted to achieve our research objectives. Consistent with previous work (Brooker & Poulin-Dubois, 2013; Crivello et al., 2017; Koenig et al., 2004; Luchkina et al., 2018) and with our predictions, infants in the unreliable condition were less likely to learn a new word, relative to infants in the reliable condition. These results indicate that infants were able to discriminate between sources of information,

TABLE 2 Performance on novel trials of SWL task regressed on correlates in unreliable condition

Predictors	*B*	*SE*	*b*	*t*	*p*	R^2	ΔR^2
Step 1							
Causal learning task	0.69	0.26	0.52	2.65	.01		0.27
						0.27	
Step 2							
Causal learning task	0.63	0.24	0.47	2.60	.01		0.14
Metacognition task	−0.10	0.05	−0.38	−0.06	.04		
						0.41	

Note: n = 21.

TABLE 3 Performance on novel trials of SWL task regressed on correlates in reliable condition

Predictors	*B*	*SE*	*b*	*t*	*p*	R^2	ΔR^2
Step 1							
Causal learning task	0.19	0.25	0.15	0.64	.42		0.02
						0.02	
Step 2							
Causal learning task	0.17	0.26	0.13	0.55	.51		0.03
Metacognition task	−0.08	0.14	−0.16	−0.69	.50		
						0.05	

Note: $n = 20$.

displaying selective trust in reliable sources relative to unreliable ones. However, some researchers caution an interpretation that would suggest that this learning is rational, given that it may appear that children use epistemic cues to inform their learning but are, in contrast to older children, unaware of the selectivity of their learning themselves (Heyes, 2016b).

In an effort to address this debate, two correlate tasks were administered to examine the predictive power of different types of abilities on infants' selective word-learning. A causal learning task was administered to obtain an index of causal learning abilities. Group performance on each of the three experimental trials was not different from chance. Performance on the "screening indirect screening-off" and "backward blocking" trials are consistent with response patterns reported by Sobel and Kirkham (2006). However, our results indicate that infants performed at chance level on the "screening-off" trials, whereas Sobel and Kirkham (2006) reported above chance performance. Contrary to what was reported by the original authors, results suggest an order effect, such that infants appear to perform progressively better across the fixed series of trials. Considering that comprehension of the task was dependent on verbal ability, perhaps these apparent differences across studies reflect variability in infants' comprehension of task instructions. Moreover, the task required goal-directed imitation that involves understanding of an agent's intentions and acting on this knowledge by imitating the goals of the actor (Sakkalou, Ellis-Davies, Fowler, Hilbrink, & Gattis, 2013). Thus, infants' gradual improvement in performance may indicate better grasp of task demands, as well as improvements in producing goal-directed behavior.

Alternatively, other researchers suggest that selectivity in social learning is associated with individual differences in more sophisticated cognitive abilities (Poulin-Dubois & Brosseau-Liard, 2016; Sabbagh et al., 2017). In the present study, a non-verbal form of metacognition was examined using a decision confidence monitoring paradigm. Consistent with results reported by Goupil and colleagues. (2016), infants searched the box longer after correctly identifying where the toy was hidden, as compared to trials where infants incorrectly identified the location of the toy. These findings suggest that more perseverance on correct trials indicate degrees of decision confidence, whereas less persistence on incorrect trials indicates a lack thereof. Additionally, infants who persisted more on correct trials, also demonstrated increased persistence on incorrect trials. This result sheds light on the nascent nature of this behavior at this age, in that the metacognitive skills tapped by this specific task do not fully reflect infants' internal monitoring of the accuracy of their own decisions.

Some support for our hypothesis was obtained, in that precursor metacognitive skills appear to be linked with 18-month-olds selective word-learning abilities exclusively in the unreliable condition. However, the pattern of results across trial type was unexpected. Infants who displayed less decision confidence on incorrect trials of the metacognition task appeared to be more willing to learn from an unreliable speaker on a selective word-learning task. Interestingly, causal learning skills also appear to play a significant role, but only in the unreliable condition. Infants who presented with better causal learning abilities were also more willing to accept an unreliable speaker's testimony. Visual inspection of the regression paths suggests a possible interaction of the two abilities. However, the extent of infants' willingness to learn from an unreliable speaker as a function of an interaction between causal learning and metacognitive abilities was not examined given the small sample sizes.

Based on these findings, it appears that infants who were more inclined to learn from an unreliable speaker, also lacked confidence in their own knowledge in a confidence-monitoring task. The uncertainty in this paradigm may relate to decisions on whether to rely on social versus personal information, or to those about "who" they should best copy (Wood et al., 2016). As such, metacognition of one's knowledge and ignorance might be central for promoting information seeking behaviors (Gliga & Southgate, 2016). A within-subjects paradigm of selective word learning would be an important context to elicit such information-seeking behavior. Moreover, it may be that under such circumstances of uncertainty, infants rely on more causal learning abilities to better learn the association between a novel label and respective object. This would be in line with a domain-general account of early word-learning (Booth, 2009), and may reflect a variation of the *copy when uncertain* social learning rule (Rendell et al., 2011). Indeed, social learning is a complex phenomenon that is unlikely to be explained by a single strategy. Future research should aim to examine young children's social learning strategies across various contexts that create uncertainty related to efficacy and efficiency of social information (Wood et al., 2016).

Moreover, the predictive power of causal learning abilities was observed to be greater than that of precursor metacognition. We propose that this may be a reflection of the immature development of these higher-order cognitive functions. As such, we anticipate that explicit metacognitive judgments play an increasingly important role in early selective social learning as children begin to verbalize their mental states. Similarly, it appears that precursor metacognitive abilities only predict infants' social learning when they are uncertain of their knowledge. We anticipate that confidence would govern successful selective learning as young children acquire more experience in metacognitive monitoring, and thus be better able to optimize learning from appropriate sources of information. Indeed, it has been proposed that knowledge confidence involves serial efforts of evaluating (a) the source of knowledge (e.g. "How does this fit with my own knowledge") and (b) developing justifications for knowing (e.g. "Do I judge this claim to be credible?") (Hofer, 2004). This, no doubt, represents a more sophisticated form of epistemological thinking that is likely not present in infancy. We, therefore, echo Heyes' (2016b) hypothesis specifying that as children develop a stronger capacity for metacognition, they will then be able to more readily adjust social learning strategies that reflect metacognitive judgments.

To date, extant research on this topic only includes two studies that investigated the link between domain-general and domain-specific mechanisms with selective social learning abilities in infancy (Crivello et al., 2017; Crivello & Poulin-Dubois, 2019). Both studies support a rich account for early selective social learning, such that infants' abilities to develop inferences about others' states of knowledge has been found to govern early selective trust. Moreover, no link was reported between selective trust abilities and domain-general abilities, namely statistical (Crivello et al., 2017) and associative learning (Crivello & Poulin-Dubois, 2019).

How can we reconcile previous research with the present findings? Several explanations can be offered to account for what appears to be a discrepancy. First, contrary to what was previously reported (Crivello et al., 2017; Crivello & Poulin-Dubois, 2019), results suggest that particular domain-general mechanisms may facilitate word-learning in a selective trust paradigm. It should be noted that the mechanisms that drive infants' abilities to represent and acquire causal knowledge is currently a topic of debate in developmental psychology. Specifically, whether associative theories can account for predictive behavior in infancy (e.g. Rescorla & Wagner, 1972), or whether more sophisticated computational models of causality underlie infants' ability to predict future behavior (Lagnado & Sloman, 2004; Steyvers, Tenenbaum, Wagenmakers, & Blum, 2003). This debate challenges the view that causal learning abilities represent "simple" mechanisms in infancy. Unlike statistical and associative learning mechanisms, causal learning abilities necessitate complex inferential capabilities that are based on principles of causality, temporal priority, spatial priority, and contingency (Bullock, Gelman, & Baillargeon, 1982). As such, the ability to develop causal inferences involving multiple potential causes and based on more complex probabilistic reasoning may represent a more sophisticated form of domain-general abilities compared to those examined in previous research.

Additionally, the causal learning task developed by Sobel and Kirkham (2006) may not reflect asocial learning that characterizes many general learning mechanisms (Heyes & Pearce, 2015). As previously mentioned, the causal learning task required infants to draw inferences about an agent's goal, and subsequently imitate goal-directed behavior. Thus, this task may rely on the ability to develop an understanding of an individual's intention in order successfully imitate their behavior. This may evoke a special advantage in the present task given the involvement of human interventions that are absent in other work (Crivello et al., 2017; Crivello & Poulin-Dubois, 2019). In fact, research supports that young children are more likely to make causal inferences when patterns of covariation are the outcome of human interventions compared to when they were not (Meltzoff, Waismeyer, & Gopnik, 2012). This is not surprising considering a history of *observational causal learning* as a dominant teaching method long before formal education is introduced (Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Rogoff, Paradise, Arauz, Correa-Chávez, & Angelillo, 2003). Given that *observational causal learning* may be a fundamental mechanism for early causal knowledge, it is possible that it guides children's selective learning more strongly as they become adept at making sense of causal interactions.

Subsequently, we examined a domain-specific ability that was initially thought to only emerge during the preschool period (Flavell, 1999; Sodian et al., 2012). We investigated metacognition of one's own ignorance, demonstrated at 18-months of age (Goupil et al., 2016), whereas previous efforts to examine the correlates of selective trust in infancy investigated ToM abilities—those that have been shown to emerge as early as 7-months (Kovács, Téglás, & Endress, 2010). Although evidence of infant ToM rests on a similar debate surrounding its origins (see Heyes, 2014; Poulin-Dubois & Yott, 2017; Ruffman, 2014; Scott & Baillargeon, 2014), it appears that there may be more opportunity for the development of mental state attribution abilities relative to an understanding of one's own knowledge (but see Gonzales, Fabricius, & Kupfer, 2018; Harris, Yang, & Cui, 2017; Meltzoff, 1999 for different views). Recent longitudinal research provides support for the primacy of ToM over metacognition (Ebert, 2015). Thus, ToM abilities may be better predictors of early selective trust as compared to metacognition, given that infants may show more understanding of others' knowledge relative to their own. Moreover, the nature of the metacognitive task may also account for the current pattern of results. That is, the uncertainty monitoring paradigm may only reflect an implicit understanding of infants' own mental states—an understanding that we share with non-human animals (see De Waal, 2016 for a review). A more explicit understanding of one's own knowledge and ignorance may better account for successful selective social learning (Heyes, 2016b).

In conclusion, the present set of findings informs the heated debate between rich and lean approaches to early selective social learning. This is the first investigation to provide preliminary support that both implicit metacognitive abilities and causal learning skills may be related to 18-month-olds stronger propensity to learn from an unreliable speaker. Findings may reflect a variation of the copy when uncertain social learning rule, in that infants may draw on causal learning to learn a new word—irrespective of the speaker's competency—when uncertain of their own knowledge. Future research initiatives should examine the predictive power of more explicit forms of metacognitive awareness on early selective trust.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author, Olivia Kuzyk.

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