Journal of Experimental Child Psychology 130 (2015) 67–78

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Connecting the dots from infancy to childhood: A longitudinal study connecting gaze following, language, and explicit theory of mind

Rechele Brooks [a,b,*], Andrew N. Meltzoff [a,c]

[a] *Institute of Learning & Brain Sciences, University of Washington, Seattle, WA 98195, USA*
[b] *Department of Psychiatry & Behavioral Science, University of Washington, Seattle, WA 98195, USA*
[c] *Department of Psychology, University of Washington, Seattle, WA 98195, USA*

ARTICLE INFO

Article history:
Received 17 April 2014
Revised 22 September 2014
Available online 23 October 2014

Keywords:
Gaze following
Language
Social cognition
Mental-state terms
Theory of mind
Longitudinal study

ABSTRACT

This longitudinal study tested the same children at three time points: infancy (10.5 months of age), toddlerhood (2.5 years of age), and early childhood (4.5 years of age). At 10.5 months, infants were assessed experimentally with a gaze-following paradigm. At 2.5 years, children's language skills were measured using the MacArthur–Bates Communicative Development Inventories. At 4.5 years, children's explicit theory of mind was assessed with a standard test battery. Analyses revealed that infants with higher gaze-following scores at 10.5 months produced significantly more mental-state words at 2.5 years and that children with more mental-state words at 2.5 years were more successful on the theory-of-mind battery at 4.5 years. These predictive longitudinal relationships remained significant after controlling for general language, maternal education, and nonsocial attention. The results illuminate the bridging role that language plays in connecting infants' social cognition to children's later understanding of others' mental states. The obtained specificity in the longitudinal relations informs theories concerning mechanisms of developmental change.

* Corresponding author at: Institute of Learning & Brain Sciences, University of Washington, Box 357988, Seattle, WA 98195, USA.

E-mail address: recheleb@uw.edu (R. Brooks).

http://dx.doi.org/10.1016/j.jecp.2014.09.010
0022-0965/

Introduction

By 4 or 5 years of age, children exhibit an explicit understanding of the representational nature of beliefs (e.g., Gopnik & Astington, 1988; Perner, 1991; Wellman, Cross, & Watson, 2001). At younger ages, they understand interrelationships among perception, desire, and intentional action, which are also integral to the development of a "theory of mind" (ToM) or "mentalizing" (e.g., Flavell, 2004; Meltzoff, 1995; Repacholi & Slaughter, 2003; Wellman, Phillips, & Rodriguez, 2000; Williamson, Brooks, & Meltzoff, 2013). In this article, we focus on even earlier development—infant gaze following and children's talk about the mind. Studying gaze following and its downstream effects provides insights into mechanisms of change in development and also informs discussions about the early identification and treatment of children with autism spectrum disorders who have deficits in gaze following (Jones & Klin, 2013; Mundy, Sullivan, & Mastergeorge, 2009; Toth, Munson, Meltzoff, & Dawson, 2006). Here, we report a longitudinal study with typically developing children that connects the dots between early gaze following, mental-state language use, and later ToM as measured by a standard test battery (Wellman & Liu, 2004).

At a theoretical level, gaze following has been argued to relate to a child's concept of mind via at least two routes. First, it has been thought of as a front-end ability that triggers or enables further growth along the ToM trajectory (Baron-Cohen, 1995). Second, gaze following promotes early word learning (Baldwin, 1993, 2000; Brooks & Meltzoff, 2005, 2008; Carpenter, Nagell, & Tomasello, 1998), and this verbal advantage has been argued to support and engender perspective taking and mentalizing. On the other hand, it has been suggested that infant gaze following may be unrelated to conceptualizing mental states because gaze following during early infancy could simply be an orienting response to physical movement or spatial cues (e.g., Corkum & Moore, 1998; Doherty, 2006; Doherty & Anderson, 1999).

Understanding visual perception and ToM

Children's understanding of visual perception is a key aspect of their grasp of others' mental states (e.g., Gopnik & Astington, 1988; Lohmann & Tomasello, 2003; Meltzoff & Brooks, 2008; Pratt & Bryant, 1990; Wellman et al., 2000). Intervention studies provide the strongest evidence; training preschoolers on perception tasks improves their understanding of false belief (Slaughter & Gopnik, 1996). It may be that learning about other people's visual perception (which has a bodily component in terms of head and eye direction) gives children leverage to understand deeper, less visible mental states such as beliefs.

A nascent reaction to the direction of people's gaze begins during early infancy. At 6 to 9 months of age, infants turn in the same direction that a person orients (Butterworth & Jarrett, 1991; Corkum & Moore, 1998; Gredebäck, Fikke, & Melinder, 2010). By 9 to 12 months of age, infants connect the looker to a focal object (Carpenter et al., 1998; Johnson, Ok, & Luo, 2007; Sodian & Thoermer, 2004; Woodward, 2003). By 10 to 12 months of age, infants selectively follow the head turns of a person who has open eyes more often than closed eyes, suggesting that infants recognize that people see with their eyes and that infants are not simply responding to salient head movement cues (Brooks & Meltzoff, 2002). By 12 to 18 months of age, a randomized control training study demonstrated that infants use their own visual experiences (with a visual barrier) to interpret when another person can and cannot see an object (Meltzoff & Brooks, 2008), providing strong evidence for construing gaze in a mentalistic framework.

Language development and ToM

Children's language has consistently been shown to influence ToM development (Milligan, Astington, & Dack, 2007; Peterson, Wellman, & Liu, 2005). Many of children's conversations with adults and peers concern mental states (de Rosnay & Hughes, 2006). Based on their social interactions in everyday settings, children increase their mental-state vocabulary and enrich their understanding of others' desires, emotions, and beliefs (Dunn, Brown, Slomkowski, Tesla, & Youngblade, 1991;

Ruffman, Slade, & Crowe, 2002). Children's production of mental-state terms is specifically related to their understanding of beliefs (Ensor & Hughes, 2008; Meins, Fernyhough, Arnott, Leekam, & de Rosnay, 2013).

Longitudinal prediction studies

Researchers have begun to examine longitudinal relationships between gaze following and later social–cognitive understanding. Kristen, Sodian, Thoermer, and Perst (2011) assessed gaze following by having an adult look, vocalize, and point at a target. They found that infants' responses to this multimodal cue predicted later use of mental-state words. Because the adult's presentation included vocalizations, it is unclear how much infants relied exclusively on the adult's *gaze* to localize the target. Infants' sensitivity to the adult vocalizations themselves could have been a factor in the obtained predictive relationship with language. Indeed, tests of infant following that disallowed adult vocalization did not relate to later performance on mental-state tasks (Colonnesi, Rieffe, Koops, & Perucchini, 2008).

Other studies have measured infant behaviors that were not specifically gaze following per se but involved the eyes, such as the number of gaze shifts infants made when looking between an adult and a target object. Using this measure, there are some reports of correlations between infants' gaze shifting and later understanding of mental states (Charman et al., 2000; Nelson, Adamson, & Bakeman, 2008). Although these gaze shifts show that infants can disengage their attention from an object to look at an adult, they do not implicate gaze following per se. Such gaze shifts may reflect infants' growing capacity for attentional control, which may relate to later ToM through an executive function pathway.

The general issue of infant attentiveness and attentional control has not been controlled in previous reports of how infant responses to adult gaze may relate to language and ToM development. General attentiveness is an untested "third factor" that could mediate obtained relationships between gaze following and other concurrent or subsequent social cognition (e.g., Colonnesi et al., 2008; Kristen et al., 2011).

Study rationale and aims

To begin to connect the dots in a longitudinal study, we tested the same children at three points in development: infancy (10.5 months of age), toddlerhood (2.5 years of age), and early childhood (4.5 years of age) and measured gaze following, productive vocabulary (including mental-state terms), and explicit ToM, respectively. A strength of this study is that we examined the specificity of the longitudinal relations. The relations were examined while controlling for general language and maternal education, which are known to be mediators of longitudinal relationships in social cognition (e.g., Cutting & Dunn, 1999; Hughes et al., 2014). We also assessed infants' looking during a nonsocial attention task to provide control data on infants' general visual attentiveness to targets.

The current work capitalized on the opportunity to retest children who participated in a nonverbal assessment of gaze following when they were infants (Brooks & Meltzoff, 2008). We followed the children longitudinally to assess (a) whether infants' gaze following at 10.5 months of age specifically predicts toddlers' acquisition of mental-state terms at 2.5 years of age and (b) whether differences in these early skills predict children's later scores on a standard ToM battery at 4.5 years of age.

Method

Participants

A total of 32 infants (16 boys) were originally tested at 10.5 months of age (*M* = 10.53 months, *SD* = 0.54) in a study of gaze following (Brooks & Meltzoff, 2008). In the longitudinal follow-up reported here, 5 of the original families were unable to participate at 2.5 years of age because they declined (*n* = 1), did not have time to complete forms (*n* = 2), or could not be reached (*n* = 2). Thus, 27 children (14 boys) were assessed when they were 2.5 years old (M = 2.51 years, SD = 0.02). Of these children, 19 (11 boys) were retested when they were 4.5 years old (M = 4.53 years, SD = 0.07). The other 8 children were unable to participate at 4.5 years because their parents declined (n = 1), moved (n = 3), or could not be reached (n = 4). In total, 59% (19 of 32) of the children originally tested during early infancy provided complete data at all time points through 4.5 years of age, which is comparable to (a) the retention rates of other longitudinal work (Wellman, Lopez-Duran, LaBounty, & Hamilton, 2008; Yamaguchi, Kuhlmeier, Wynn, & vanMarle, 2009) and (b) the final sample size reported in previous longitudinal studies spanning from infancy to preschool tests of ToM (Aschersleben, Hofer, & Jovanovic, 2008; Charman et al., 2000).

Parents identified 74% of the children as White, 5% as Black, and 21% as more than one ethnicity/race for the longitudinal group. Mothers reported their educational degrees as ranging from high school to advanced degrees, with a mean of a 4-year university degree (M = 16.63 years of schooling, SD = 1.98). Families received a small gift at each assessment.

Procedures and measures

The longitudinal study included data from 10.5 months, 2.5 years, and 4.5 years of age.

Test at 10.5 months

Infants sat on their parent's lap across the table from an experimenter in the laboratory. The gaze-following task was administered before the nonsocial-looking task to prevent task interference. (The latter task had activated targets, which could influence the infants' gaze-following responses.)

Gaze following. Infants participated in a gaze-following task with distal stationary targets (9 cm diameter × 16 cm tall). There were two identical colorful targets, 75° to the left and right of the infant (135 cm away from infant midline), placed at the infant's eye level on pedestals. As reported by Brooks and Meltzoff (2008), there were four 6.5-s test trials in the original assessment of gaze following. The experimenter made eye contact with the infant to confirm that the infant was at midline before looking at a target. The experimenter silently turned her head and eyes with a neutral expression toward one of the two distal targets.

Infants' looking was scored from video by a coder who was kept blind to the direction of the experimenter's head turn and the hypotheses of the study. As is common in the laboratory-based gaze-following literature, the first "correct look" in each trial was scored when the infant's eyes aligned with the experimenter's target (e.g., Gredebäck et al., 2010) and used in the statistical analysis. The "gaze-following" score was calculated as the average duration of correct looks—that is, the total duration of correct looks divided by the number of correct looks (as scored by Brooks & Meltzoff, 2008). (A score of 0 was given to infants who had no correct looks.) An independent coder also scored 25% of the infants' videos to test for coder agreement. Intercoder agreement (Cohen's κ) was .95 for gaze following.

Nonsocial looking. A nonsocial-looking task was also administered. This task used remotely activated mechanical targets (24 cm long × 12 cm wide × 14 cm tall) that sat on the pedestals. The two identical targets were toy pigs programmed to move their noses and tails while emitting a sound and then to move their legs (although the targets were anchored to stay in one place). During the two trials, the experimenter remained neutral with a pleasant demeanor and looked forward without looking at the activated targets. One infant did not complete this task because of mechanical problems with the targets.

A coder scored infants' looking from video and was kept blind to the target activation and the hypotheses of the study. The "nonsocial-looking" score was the average duration of correct looks across the two trials. An independent coder scored 25% of the infants' videos for coder agreement. The intercoder agreement (Cohen's κ) was .98.

Test at 2.5 years

We assessed children's productive vocabulary. Parents were mailed two standardized forms from the MacArthur–Bates Communicative Development Inventories (CDI): the Words and Sentences form (680 words appropriate for ages 1.5–2.5 years) and the Level III form (100 words appropriate for ages 2.5–3.1 years). The forms are valid and reliable measures of children's productive vocabulary (Fenson et al., 2007). Two language scores were derived from the CDI forms (similar to Meins et al., 2013).

Mental-state terms. The CDI forms yielded a score for children's production of 15 mental-state terms from three categories: *cognition* (4 words: "forget," "idea," "pretend," and "think"), *desire* (3 words: "need," "wanna" or "want to," and "wish"), and *emotion* (8 words: "angry," "happy," "hate," "like," "love," "mad," "sad," and "scared"). These words were the most common mental-state terms produced by young children (e.g., Bartsch & Wellman, 1995; Bretherton & Beeghly, 1982; Brown & Dunn, 1991; Shatz, Wellman, & Silber, 1983).

Nonmental terms. The CDI forms also yielded a score for children's production of nonmental vocabulary. Most of the mental terms were predicates (verbs and adjectives, which are categorized as action and descriptive words on the CDI; Bates et al., 1994). Thus, the "nonmental terms" were the number of action and descriptive words minus the number of mental-state terms.

Test at 4.5 years

Children were evaluated in the laboratory by experimenters who were kept blind to the results of the children's previous assessments.

Verbal ability. Children's verbal comprehension was assessed with the Peabody Picture Vocabulary Test (PPVT, 3rd edition), which has high internal consistency and validity (Dunn & Dunn, 1997). The administration of the PPVT was abridged to word lists for children aged 5 to 7 years to test age-appropriate verbal comprehension. Those items were assigned raw scores based on PPVT scoring instructions, resulting in a possible range of 25 to 72.

ToM. The experimenter administered five tasks from Wellman and Liu's (2004) explicit ToM scale and an additional false-belief task (as in Wellman et al., 2008). D. Liu (personal communication, October 2006) provided a minor modification to one task (i.e., to use the hidden emotion task from LaBounty, Wellman, Olson, Lagattuta, & Liu, 2008) and provided the change-of-location task. A fixed presentation order was used for the six tasks: (1) diverse desires, (2) knowledge acquisition, (3) false belief (unexpected contents), (4) diverse beliefs, (5) hidden emotions, and (6) false belief (changed location).

Scoring rules from Wellman and Liu (2004) were used to code children from video. Children were scored as "correct" if they correctly answered the test *and* the associated control questions. Two scores were derived as described by Wellman and colleagues (2008). The overall ToM score was the total number of correct scores from the first five tasks (possible range of 0–5). The "false-belief" (FB) score was the total number of correct scores from Tasks 3 and 6 (possible range of 0–2).

In addition to the primary scorer, an independent coder reviewed 25% of the children's videos to test coder agreement. The coder was blind to the children's previous scores. Intercoder agreement was 1.00 (Cohen's κ).

Results

Preliminary analyses

Table 1 presents the descriptive statistics for the children in the longitudinal study. The infants who were assessed at 2.5 and 4.5 years of age had scores consistent with the entire group of infants originally tested at 10.5 months of age ($N = 32$). More specifically, both the gaze-following and nonsocial-looking scores were not significantly different between infants assessed at 2.5 years ($N = 27$) and those who were not assessed at 2.5 years ($ps > .30$), nor were there any significant differences between

Table 1
Mean scores for dependent measures.

Dependent measure	Mean	*SD*	Range
	10.5 months		
Gaze following[a]	1.34	1.22	0–4.12 s
Nonsocial looking[b]	3.95	1.67	1.20–6.50 s
	2.5 years[a]		
Nonmental terms	128.37	36.66	35–155 words
Mental-state terms	10.11	4.22	2–15 words
Cognition terms	2.22	1.55	0–4 words
Desire terms	2.07	0.83	0–3 words
Emotion terms	5.81	2.24	1–8 words
	4.5 years[c]		
PPVT score	63.53	4.03	56–70 raw score
Theory-of-mind score	3.63	1.16	2–5 correct
False-belief score	1.11	0.94	0–2 correct

[a] $N = 27$.
[b] $N = 26$.
[c] $N = 19$.

infants' scores for children seen at 4.5 years ($N = 19$) and those who did not return to participate at 4.5 years (*ps* > .20).

Main analyses

First, longitudinal associations were assessed using Pearson correlations. (Nonparametric Spearman rank–order correlations yielded similar results.) Second, longitudinal relationships were submitted to hierarchical regression analyses to examine whether longitudinal associations were significant after controlling for general language. Follow-up analyses were conducted with individual categories of mental states.

Longitudinal relationships between infant scores and language at 2.5 years

The behavior from infant social and nonsocial gaze tasks were tested as correlates of nonmental and mental-state terms.

Gaze following. Infant gaze following at 10.5 months of age was evaluated as a predictor of children's language at 2.5 years of age. Infant gaze following was highly correlated with children's subsequent use of mental-state terms at 2.5 years, $r(25) = .53$, $p = .005$. Infant gaze following was also correlated with the use of nonmental terms at 2.5 years, $r(25) = .40$, $p = .041$.

A secondary analysis tested whether socioeconomic status (SES) was a covariate of measures at 2.5 years of age. Maternal education (as a proxy for SES) did not significantly correlate with toddler mental-state terms, $r(25) = .11$, $p = .59$, or nonmental terms, $r(25) = -.007$, $p = .97$, nor did it correlate with infant gaze following, $r(25) = .21$, $p = .29$.

A hierarchical regression analysis tested the predictors of mental-state terms at 2.5 years of age (Table 2), evaluating whether the relationship between gaze following and mental-state terms remained significant after accounting for general vocabulary. The analysis included only measures with significant correlations in this study to limit the number of variables. In Step 1, nonmental terms (2.5 years) were entered as a control for general vocabulary and were found to be a significant predictor of concurrent mental-state terms ($p < .0001$). In Step 2, gaze following significantly predicted mental-state terms ($p = .043$) after controlling for nonmental terms. Thus, infants who had higher gaze-following scores subsequently used more mental-state terms at 2.5 years even after accounting for their general vocabulary.

At an even finer level, infant gaze following at 10.5 months of age was positively correlated with *individual categories* of mental-state terms at 2.5 years of age. Gaze following significantly correlated

Table 2
Predictors of mental-state terms at 2.5 years of age tested with hierarchical regression analysis.

Steps and variables	β	ΔR^2	ΔF	p
Step 1		.72	65.63	<.0001
Nonmental terms (2.5 years)	.85			<.0001
Step 2		.04	4.55	.043
Nonmental terms (2.5 years)	.76			<.0001
Gaze following (10.5 months)	.23			.043

Note. $N = 27$.

with the number of cognition, desire, and emotion words (*r*s ranged from .45 to .54 and *p*s ranged from .018 to .004). Gaze following still significantly correlated with cognition terms after controlling for nonmental terms, partial $r(24) = .40$, $p = .043$. Gaze following did not significantly correlate with the two other categories after controlling for nonmental terms: desire, partial $r(24) = .32$, $p = .11$; emotion, partial $r(24) = .24$, $p = .23$. In the Discussion, we examine how these findings of "specificity" fit with and also advance previous longitudinal studies (Kristen et al., 2011).

Nonsocial looking (control). Infants' nonsocial looking at 10.5 months of age did not significantly correlate with their nonmental terms at 2.5 years of age, $r(24) = .22$, $p = .28$. Nonsocial looking also did not significantly correlate with mental-state terms at 2.5 years, $r(24) = .29$, $p = .15$. Thus, infant nonsocial attention did not relate to the subsequent use of mental or nonmental terms.

A hierarchical regression analysis tested whether mental-state terms were predicted by gaze following after controlling for nonsocial looking. In Step 1, nonsocial looking was entered as a control for general (nonsocial) attention ($\beta = .29$, $R^2 = .08$, $p = .15$). In Step 2, gaze following was still a significant predictor of mental-state terms ($\beta = .49$, $p = .016$), $\Delta R^2 = .21$, $F(1, 23) = 6.71$, $p = .016$, after controlling for nonsocial looking ($\beta = .10$, $p = .59$). Thus, gaze following, rather than general visual attentiveness, predicted mental-state terms, again suggesting interesting specificity, as discussed later.

Longitudinal relationships between toddler language and ToM at 4.5 years

Nonmental terms at 2.5 years of age correlated with ToM scores at 4.5 years of age, $r(17) = .48$, $p = .038$, but not when PPVT (at 4.5 years) was controlled, partial $r(16) = .29$, $p = .25$. Nonmental terms did not significantly correlate with FB scores at 4.5 years, $r(17) = .35$, $p = .14$. Infant gaze following and nonsocial looking were not significantly correlated with ToM and FB at 4.5 years (*p*s > .45), a point taken up in the Discussion.

The use of mental-state terms at 2.5 years of age was evaluated as a predictor of ToM and FB scores at 4.5 years of age. Children's mental-state terms at 2.5 years significantly predicted their ToM scores at 4.5 years, $r(17) = .57$, $p = .01$; with PPVT controlled, partial $r(16) = .40$, $p = .10$. They showed even stronger predictions for FB scores in particular, $r(17) = .61$, $p = .005$; with PPVT controlled, partial $r(16) = .50$, $p = .04$.

A secondary analysis examined whether verbal ability and SES were covariates of false belief at 4.5 years of age. Concurrent PPVT scores (an index of children's verbal ability) significantly correlated with FB scores, $r(17) = .48$, $p = .026$. Maternal education (a proxy for SES) significantly correlated with FB scores, $r(17) = .56$, $p = .012$, and with PPVT, $r(17) = .46$, $p = .045$.

A hierarchical regression analysis tested the predictors of false-belief understanding at 4.5 years of age (Table 3). This analysis evaluated whether the relationship between mental-state terms and FB scores remained significant after accounting for SES and general verbal ability. The analysis included only the measures with significant correlations so as to limit the number of variables. In Step 1, two control measures were entered: (a) maternal education to control for SES and (b) PPVT (at 4.5 years) to control for verbal ability. Together these measures significantly ($p = .032$) predicted FB scores at 4.5 years. In Step 2, mental-state terms significantly ($p = .034$) predicted FB scores after controlling for maternal education and general verbal ability. Thus, toddlers who used more mental-state terms

Table 3
Predictors of false-belief performance at 4.5 years of age tested with hierarchical regression analysis.

Steps and variables	β	ΔR^2	ΔF	p
Step 1		.35	4.31	.032
Maternal education	.46			.058
PPVT (4.5 years)	.21			.37
Step 2		.17	5.46	.034
Maternal education	.43			.052
PPVT (4.5 years)	−.06			.79
Mental-state terms (2.5 years)	.51			.034

Note. $N = 19$.

at 2.5 years of age also succeeded on more false-belief tasks even after controlling for maternal education and children's verbal ability.

At a finer level of detail, follow-up analyses revealed that a particular category of mental-state terms at 2.5 years of age significantly correlated with performance on false-belief tasks at 4.5 years of age after controlling for maternal education and children's general verbal ability at 4.5 years. After controlling for maternal education and PPVT, cognition terms were significantly correlated with FB scores, partial $r(15) = .49$, $p = .046$. Desire and emotion terms did not reach statistical significance, partial $r(15) = .48$, $p = .053$, and partial $r(15) = .45$, $p = .073$, respectively. Thus, children who used more cognition terms at 2.5 years had better performance on explicit false-belief tasks at 4.5 years even after controlling for general language ability and maternal education.

Discussion

The current work shows longitudinal predictive relations among infant gaze following, toddler language, and childhood ToM performance even after controlling for children's general verbal ability. Two specific longitudinal relations that are relevant to developmental theory emerged. The first is the significant connection from infants' gaze following at 10.5 months of age to their later production of mental-state terms at 2.5 years of age. Gaze following was assessed before infants began talking, yet it predicted the use of mental-state terms more than 1.5 years later. Crucially, the relationship between gaze following and mental-state terms was not explained by infant general (nonsocial) attention or more general toddler vocabulary size. The second key finding was that children's use of mental-state terms at 2.5 years strongly predicted their later understanding of false belief at 4.5 years.

These results suggest that infant gaze following plays a quantifiable developmental role in children's early linguistic and social–cognitive development. Gaze following relates to later production of mental-state terms (especially about cognition). The link from gaze following to cognition words accords with recent work about children's rich understanding of visual perception (Moll, Meltzoff, Merzsch, & Tomasello, 2013; Moll & Tomasello, 2006). Perhaps infants' own experiences with seeing supports an understanding of how others visually acquire information—Meltzoff's (2007, 2013) "like me" idea. This cognitive understanding could then be coded in language—following models of how early cognition supports specific aspects of semantic development (e.g., Carey, 2009; Gopnik & Meltzoff, 1986; Markman, 1989).

The current results assess the specificity of developmental relations and support, but go beyond, the more global view that children's verbal ability is important for the development of ToM (for reviews, see Milligan et al., 2007; San Juan & Astington, 2012). In the findings reported here, general verbal ability was examined and controlled. First, we used a list of nonmental terms to closely match to the mental-state terms. Second, we assessed and controlled for general verbal ability at 4.5 years of age using a standardized test (PPVT). With these controls for language, gaze following predicted later mental-state terms and mental-state terms predicted later ToM, suggesting theoretically relevant specificity in development.

At first blush, one might be surprised that infant gaze-following skills did not directly predict preschooler ToM performance at 4.5 years of age. A close reading of the previous longitudinal studies indicates that this is not unexpected, although a small sample size may be a limiting factor in the current study. Past studies assessing correlations between various measures of joint attention and later social–cognitive tasks have yielded mixed results even when some used larger samples than the current study (e.g., Camaioni, Perucchini, Bellagamba, & Colonnesi, 2004; Charman et al., 2000; Colonnesi et al., 2008). A possible procedural reason for differences among the findings is that some studies incorporate adult vocalizations into their infant assessment (e.g., Kristen et al., 2011; Nelson et al., 2008). In such studies, it is difficult to know which factors (i.e., gaze or language sensitivity) underlie the observed longitudinal relationships. In the current study, the infant gaze-following assessment intentionally *did not include verbal cues;* despite this, infants' gaze following predicted mental-state terms (even after controlling for children's general vocabulary). Thus, gaze following related to mental-state vocabulary over and above children's more general language competence.

The current findings differ from longitudinal studies that have assessed other aspects of infant social cognition, notably the understanding of goal-directed acts. These studies reported significant predictive relationships between infant performance and later explicit theory of mind even after "third factors" that might mediate this relation were controlled (e.g., Aschersleben et al., 2008; Wellman et al., 2008; Yamaguchi et al., 2009). One way of reconciling this apparent difference is to recognize that infant social cognition might not start as a fully integrated psychological system. Particular infant behaviors (e.g., understanding goal-directed acts) may be contributors to aspects of subsequent social cognition, whereas other infant behaviors (e.g., gaze following) have a different effect on linguistic and social–cognitive development (see also Charman et al., 2000; Flom, Lee, & Muir, 2007; Gopnik & Meltzoff, 1997; Kristen et al., 2011; Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Mundy & Newell, 2007).

Gaze following at 10.5 months of age specifically related to subsequent production of mental-state terms at 2.5 years of age. It has been argued that, in principle, gaze following could reflect children's general attentional system (e.g., Mundy et al., 2009), but past longitudinal work did not control for such a possibility. In the current work, nonsocial looking was specifically assessed as an index of general attentiveness. Even after controlling for nonsocial looking, gaze following remained a significant predictor of children's use of mental-state terms. (The link between infant gaze following and subsequent mental-state language also suggests that infant gaze following is not wholly reducible to the leanest interpretation of following salient physical movements in the visual field.) Following the gaze of others may help infants to relate visible behavior (e.g., looking) to invisible properties of people (e.g., seeing or knowing), supporting the acquisition of mental-state terms especially for cognition. Such a process is highly compatible with the "specificity hypothesis" linking specific aspects of early cognition with specific aspects of semantic development (Gopnik & Meltzoff, 1986, 1987, 1997).

Gaze following provides infants with a special avenue for learning from conversations with parents, caregivers, and siblings. Just as infants who follow a person's line of regard are given a boost in learning the names of objects (e.g., Baldwin, 2000), infants may also gain an advantage in learning mental-state terms by following their parents' looks during discussions. Gaze followers can identify the topic (e.g., a person, object, or action) and learn about mental states when hearing their parents talk about psychological experiences connected to that sight (e.g., Repacholi, Meltzoff, Rowe, & Spiewak Toub, 2014). Examinations of parent–child interactions show that parents' individual styles of using language to highlight mental states (sometimes called "mind-mindedness") contribute to children's understanding of the mind (Dunn et al., 1991; Ensor & Hughes, 2008; LaBounty et al., 2008; Meins et al., 2013; Perner, Ruffman, & Leekam, 1994; Ruffman et al., 2002; Sabbagh & Callanan, 1998). Other work shows that parents tend to talk about higher level mental states (e.g., "remember") yet talk less often about direct perceptual states (e.g., "see") once their infants become consistent gaze followers (Slaughter, Peterson, & Carpenter, 2008), suggesting complex developmental relations and intuitive pedagogy.

The current work has limitations. One limitation is that it had a relatively small sample size (yet the sample size was similar to other longitudinal studies in this area, including Aschersleben et al., 2008, and Yamaguchi et al., 2009). A second limitation is that it is a correlational study and causal pathways were not established. Future longitudinal work with a larger sample and additional assessments would permit the use of more detailed regression models to address causal pathways from a statistical viewpoint (e.g., Hughes, Ensor, & Marks, 2011; Meins et al., 2013). A randomized control intervention would be a stronger test of causal relations. Specifically, one could design an intervention to change infant gaze following (e.g., Kasari, Paparella, Freeman, & Jahromi, 2008; Meltzoff & Brooks, 2008; Mundy et al., 2009) with the a priori prediction, based on the current report, that this intervention will affect subsequent mental-state language and explicit ToM.

The current study also has some notable strengths. The study longitudinally followed an existing group of infants assessed before they were producing language and tracked them into early childhood. From a methodological viewpoint, it used different experimenters for assessing infant gaze behaviors and later ToM performance, thereby rigorously preserving experimental blindness. Moreover, we made a special effort to test all children so that they were tightly clustered around their target ages. All but 1 child at the 2.5-year test was assessed within 20 days of the target age of 30 months; all but 3 children at the 4.5-year visit were assessed within 20 days of the target age of 54 months. Given that children develop rapidly, this tight age clustering may have helped to uncover relationships that more liberal protocols for age may have missed. Finally, the current work controlled for salient third factors that might affect the observed relations; the predictive relationships remained significant after controlling for maternal education, infants' nonsocial attention, and children's verbal skills.

Taken together, the pattern of findings helps to connect the dots among infancy, language, and the emergence of an explicit ToM during childhood. The current work specifically links infants' gaze following to their subsequent production of mental-state terms (not just to general vocabulary development). The results suggest that infants' gaze following feeds children's linguistic coding of psychological concepts (especially cognition words), which in turn supports and predicts explicit ToM development.

These findings have implications for children with pervasive developmental disorders characterized by deficits in gaze following—for example, children with autism spectrum disorders—because they would be expected to have downstream deficits following the pathways described here. Interventions seeking to improve gaze following could, in theory, improve children's developing mental-state language and their emerging concept of mind. By understanding basic developmental pathways and mechanisms of change, we can design more specific and effective treatment protocols for children who might profit from early interventions (Meltzoff et al., 2009). This would allow us to connect the dots more completely in both theory and practice.

Acknowledgments

We gratefully acknowledge support from the National Science Foundation (SMA-0835854) and from the Institute for Learning & Brain Science at the University of Washington. We thank Calle Fisher, Craig Harris, and Linden Hale for their assistance.

References

Aschersleben, G., Hofer, T., & Jovanovic, B. (2008). The link between infant attention to goal-directed action and later theory of mind abilities. *Developmental Science, 11*, 862–868.
Baldwin, D. A. (1993). Early referential understanding: Infants' ability to recognize referential acts for what they are. *Developmental Psychology, 29*, 832–843.
Baldwin, D. A. (2000). Interpersonal understanding fuels knowledge acquisition. *Current Directions in Psychological Science, 9*, 40–45.
Baron-Cohen, S. (1995). *Mindblindness: An essay on autism and theory of mind*. Cambridge, MA: MIT Press.
Bartsch, K., & Wellman, H. M. (1995). *Children talk about the mind*. New York: Oxford University Press.
Bates, E., Marchman, V., Thal, D., Fenson, L., Dale, P., Reznick, J. S., et al (1994). Developmental and stylistic variation in the composition of early vocabulary. *Journal of Child Language, 21*, 85–123.
Bretherton, I., & Beeghly, M. (1982). Talking about internal states: The acquisition of an explicit theory of mind. *Developmental Psychology, 18*, 906–921.
Brooks, R., & Meltzoff, A. N. (2002). The importance of eyes: How infants interpret adult looking behavior. *Developmental Psychology, 38*, 958–966.
Brooks, R., & Meltzoff, A. N. (2005). The development of gaze following and its relation to language. *Developmental Science, 8*, 535–543.
Brooks, R., & Meltzoff, A. N. (2008). Infant gaze following and pointing predict accelerated vocabulary growth through two years of age: A longitudinal, growth curve modeling study. *Journal of Child Language, 35*, 207–220.
Brown, J. R., & Dunn, J. (1991). "You can cry, mum": The social and developmental implications of talk about internal states. *British Journal of Developmental Psychology, 9*, 237–256.
Butterworth, G., & Jarrett, N. (1991). What minds have in common is space: Spatial mechanisms serving joint visual attention in infancy. *British Journal of Developmental Psychology, 9*, 55–72.

Camaioni, L., Perucchini, P., Bellagamba, F., & Colonnesi, C. (2004). The role of declarative pointing in developing a theory of mind. *Infancy, 5*, 291–308.
Carey, S. (2009). *The origins of concepts*. New York: Oxford University Press.
Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention, and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development, 63*. 4, Serial No. 255.
Charman, T., Baron-Cohen, S., Swettenham, J., Baird, G., Cox, A., & Drew, A. (2000). Testing joint attention, imitation, and play as infancy precursors to language and theory of mind. *Cognitive Development, 15*, 481–498.
Colonnesi, C., Rieffe, C., Koops, W., & Perucchini, P. (2008). Precursors of a theory of mind: A longitudinal study. *British Journal of Developmental Psychology, 26*, 561–577.
Corkum, V., & Moore, C. (1998). The origins of joint visual attention in infants. *Developmental Psychology, 34*, 28–38.
Cutting, A. L., & Dunn, J. (1999). Theory of mind, emotion understanding, language, and family background: Individual differences and interrelations. *Child Development, 70*, 853–865.
de Rosnay, M., & Hughes, C. (2006). Conversation and theory of mind: Do children talk their way to socio-cognitive understanding? *British Journal of Developmental Psychology, 24*, 7–37.
Doherty, M. J. (2006). The development of mentalistic gaze understanding. *Infant and Child Development, 15*, 179–186.
Doherty, M. J., & Anderson, J. R. (1999). A new look at gaze: Preschool children's understanding of eye-direction. *Cognitive Development, 14*, 549–571.
Dunn, J., Brown, J., Slomkowski, C., Tesla, C., & Youngblade, L. (1991). Young children's understanding of other people's feelings and beliefs: Individual differences and their antecedents. *Child Development, 62*, 1352–1366.
Dunn, L. M., & Dunn, L. M. (1997). *Peabody Picture Vocabulary Test* (3rd ed.). Circle Pines, MN: American Guidance Service.
Ensor, R., & Hughes, C. (2008). Content or connectedness? Mother–child talk and early social understanding. *Child Development, 79*, 201–216.
Fenson, L., Marchman, V. A., Thal, D. J., Dale, P. S., Bates, E., & Reznick, J. S. (2007). *MacArthur–Bates Communicative Development Inventories: User's guide and technical manual* (2nd ed.). Baltimore, MD: Paul H. Brookes.
Flavell, J. H. (2004). Development of knowledge about vision. In D. T. Levin (Ed.), *Thinking and seeing: Visual metacognition in adults and children* (pp. 13–36). Cambridge, MA: MIT Press.
Flom, R., Lee, K., & Muir, D. (Eds.). (2007). *Gaze-following: Its development and significance*. Mahwah, NJ: Lawrence Erlbaum.
Gopnik, A., & Astington, J. W. (1988). Children's understanding of representational change and its relation to the understanding of false belief and the appearance–reality distinction. *Child Development, 59*, 26–37.
Gopnik, A., & Meltzoff, A. N. (1986). Relations between semantic and cognitive development in the one-word stage: The specificity hypothesis. *Child Development, 57*, 1040–1053.
Gopnik, A., & Meltzoff, A. N. (1987). The development of categorization in the second year and its relation to other cognitive and linguistic developments. *Child Development, 58*, 1523–1531.
Gopnik, A., & Meltzoff, A. N. (1997). *Words, thoughts, and theories*. Cambridge, MA: MIT Press.
Gredebäck, G., Fikke, L., & Melinder, A. (2010). The development of joint visual attention: A longitudinal study of gaze following during interactions with mothers and strangers. *Developmental Science, 13*, 839–848.
Hughes, C., Devine, R. T., Ensor, R., Koyasu, M., Mizokawa, A., & Lecce, S. (2014). Lost in translation? Comparing British, Japanese, and Italian children's theory-of-mind performance. *Child Development Research, 2014*. http://dx.doi.org/10.1155/2014/893492. art. 893492.
Hughes, C., Ensor, R., & Marks, A. (2011). Individual differences in false belief understanding are stable from 3 to 6 years of age and predict children's mental state talk with school friends. *Journal of Experimental Child Psychology, 108*, 96–112.
Johnson, S. C., Ok, S.-J., & Luo, Y. (2007). The attribution of attention: 9-month-olds' interpretation of gaze as goal-directed action. *Developmental Science, 10*, 530–537.
Jones, W., & Klin, A. (2013). Attention to eyes is present but in decline in 2–6-month-old infants later diagnosed with autism. *Nature, 504*, 427–431.
Kasari, C., Paparella, T., Freeman, S., & Jahromi, L. B. (2008). Language outcome in autism: Randomized comparison of joint attention and play interventions. *Journal of Consulting and Clinical Psychology, 76*, 125–137.
Kristen, S., Sodian, B., Thoermer, C., & Perst, H. (2011). Infants' joint attention skills predict toddlers' emerging mental state language. *Developmental Psychology, 47*, 1207–1219.
LaBounty, J., Wellman, H. M., Olson, S., Lagattuta, K., & Liu, D. (2008). Mothers' and fathers' use of internal state talk with their young children. *Social Development, 17*, 757–775.
Lohmann, H., & Tomasello, M. (2003). The role of language in the development of false belief understanding: A training study. *Child Development, 74*, 1130–1144.
Markman, E. M. (1989). *Categorization and naming in children: Problems of induction*. Cambridge, MA: MIT Press.
Meins, E., Fernyhough, C., Arnott, B., Leekam, S. R., & de Rosnay, M. (2013). Mind-mindedness and theory of mind: Mediating roles of language and perspectival symbolic play. *Child Development, 84*, 1777–1790.
Meltzoff, A. N. (1995). Understanding the intentions of others: Re-enactment of intended acts by 18-month-old children. *Developmental Psychology, 31*, 838–850.
Meltzoff, A. N. (2007). "Like me": A foundation for social cognition. *Developmental Science, 10*, 126–134.
Meltzoff, A. N. (2013). Origins of social cognition: Bidirectional self–other mapping and the "like-me" hypothesis. In M. R. Banaji & S. Gelman (Eds.), *Navigating the social world: What infants, children, and other species can teach us* (pp. 139–144). New York: Oxford University Press.
Meltzoff, A. N., & Brooks, R. (2008). Self-experience as a mechanism for learning about others: A training study in social cognition. *Developmental Psychology, 44*, 1257–1265.
Meltzoff, A. N., Kuhl, P. K., Movellan, J., & Sejnowski, T. J. (2009). Foundations for a new science of learning. *Science, 325*, 284–288.
Milligan, K., Astington, J. W., & Dack, L. A. (2007). Language and theory of mind: Meta-analysis of the relation between language ability and false-belief understanding. *Child Development, 78*, 622–646.
Moll, H., Meltzoff, A. N., Merzsch, K., & Tomasello, M. (2013). Taking versus confronting visual perspectives in preschool children. *Developmental Psychology, 49*, 646–654.

Moll, H., & Tomasello, M. (2006). Level 1 perspective-taking at 24 months of age. *British Journal of Developmental Psychology, 24*, 603–613.

Mundy, P., & Newell, L. (2007). Attention, joint attention, and social cognition. *Current Directions in Psychological Science, 16*, 269–274.

Mundy, P., Sullivan, L., & Mastergeorge, A. M. (2009). A parallel and distributed-processing model of joint attention, social cognition, and autism. *Autism Research, 2*, 2–21.

Nelson, P. B., Adamson, L. B., & Bakeman, R. (2008). Toddlers' joint engagement experience facilitates preschoolers' acquisition of theory of mind. *Developmental Science, 11*, 847–852.

Perner, J. (1991). *Understanding the representational mind*. Cambridge, MA: MIT Press.

Perner, J., Ruffman, T., & Leekam, S. R. (1994). Theory of mind is contagious: You catch it from your sibs. *Child Development, 65*, 1228–1238.

Peterson, C. C., Wellman, H. M., & Liu, D. (2005). Steps in theory-of-mind development for children with deafness or autism. *Child Development, 76*, 502–517.

Pratt, C., & Bryant, P. (1990). Young children understand that looking leads to knowing (so long as they are looking into a single barrel). *Child Development, 61*, 973–982.

Repacholi, B., Meltzoff, A. N., Rowe, H., & Spiewak Toub, T. (2014). Infant, control thyself: Infants' integration of multiple social cues to regulate their imitative behavior. *Cognitive Development, 32*, 46–57.

Repacholi, B., & Slaughter, V. (2003). *Individual differences in theory of mind: Implications for typical and atypical development*. New York: Taylor & Francis.

Ruffman, T., Slade, L., & Crowe, E. (2002). The relation between children's and mothers' mental state language and theory-of-mind understanding. *Child Development, 73*, 734–751.

Sabbagh, M. A., & Callanan, M. A. (1998). Metarepresentation in action: 3-, 4-, and 5-year-olds' developing theories in mind in parent–child conversations. *Developmental Psychology, 34*, 491–502.

San Juan, V., & Astington, J. W. (2012). Bridging the gap between implicit and explicit understanding: How language development promotes the processing and representation of false belief. *British Journal of Developmental Psychology, 30*, 105–122.

Shatz, M., Wellman, H. M., & Silber, S. (1983). The acquisition of mental verbs: A systematic investigation of the first reference to mental state. *Cognition, 14*, 301–321.

Slaughter, V., & Gopnik, A. (1996). Conceptual coherence in the child's theory of mind: Training children to understand belief. *Child Development, 67*, 2967–2988.

Slaughter, V., Peterson, C. C., & Carpenter, M. (2008). Maternal talk about mental states and the emergence of joint visual attention. *Infancy, 13*, 640–659.

Sodian, B., & Thoermer, C. (2004). Infants' understanding of looking, pointing, and reaching as cues to goal-directed action. *Journal of Cognition and Development, 5*, 289–316.

Toth, K., Munson, J., Meltzoff, A. N., & Dawson, G. (2006). Early predictors of communication development in young children with autism spectrum disorder: Joint attention, imitation, and toy play. *Journal of Autism and Developmental Disorders, 36*, 993–1005.

Wellman, H. M., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development: The truth about false belief. *Child Development, 72*, 655–684.

Wellman, H. M., & Liu, D. (2004). Scaling of theory-of-mind tasks. *Child Development, 75*, 523–541.

Wellman, H. M., Lopez-Duran, S., LaBounty, J., & Hamilton, B. (2008). Infant attention to intentional action predicts preschool theory of mind. *Developmental Psychology, 44*, 618–623.

Wellman, H. M., Phillips, A. T., & Rodriguez, T. (2000). Young children's understanding of perception, desire, and emotion. *Child Development, 71*, 895–912.

Williamson, R. A., Brooks, R., & Meltzoff, A. N. (2013). The sound of social cognition: Toddlers' understanding of how sound influences others. *Journal of Cognition and Development*. http://dx.doi.org/10.1080/15248372.2013.824884. in press.

Woodward, A. L. (2003). Infants' developing understanding of the link between looker and object. *Developmental Science, 6*, 297–311.

Yamaguchi, M., Kuhlmeier, V. A., Wynn, K., & vanMarle, K. (2009). Continuity in social cognition from infancy to childhood. *Developmental Science, 12*, 746–752.