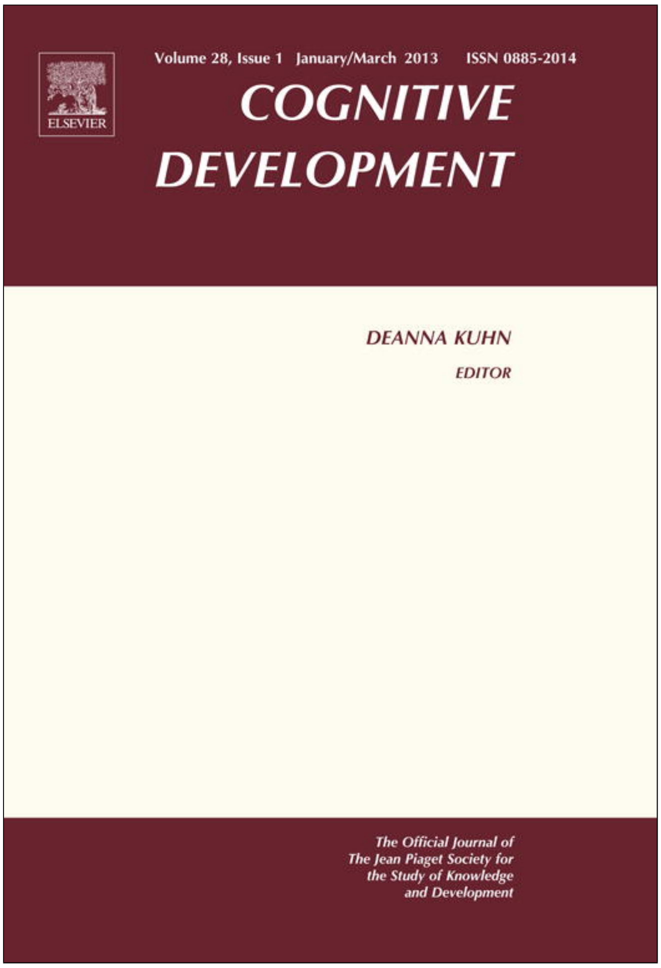
Volume 28, Issue 1 January/March 2013 ISSN 0885-2014
ELSEVIER
COGNITIVE DEVELOPMENT
DEANNA KUHN
EDITOR
The Official Journal of
The Jean Piaget Society for
the Study of Knowledge
and Development

Cognitive Development 28 (2013) 21–30

Contents lists available at SciVerse ScienceDirect

Cognitive Development

Young children show a dissociation in looking and pointing behavior in falling events

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A B S T R A C T

Studies of social cognitive reasoning have demonstrated instances of children engaging in eye gaze patterns toward correct answers even when pointing or verbal responses are directed toward incorrect answers. Findings such as these have spawned seminal theories, yet no consensus has been reached regarding the characteristics of the knowledge guiding these responses. We tested 2-year-olds' eye gaze and pointing behavior in an occluded falling event to examine these behaviors within the domain of physical reasoning. In the simplest variant of the task, all children showed correct gaze to the final location of a ball dropped down a curved tube, but only a subset of these children pointed to the correct location. (Others pointed reliably to a location directly below the release point.) With two tubes, all children directed the majority of looking and pointing responses to this erroneous location. The findings are considered in relation to existing models of representational change.

1. Introduction

Children's verbal, pointing, and reaching errors shed light on the characteristics of early representational frameworks and have helped to inform theory regarding the mechanisms underlying conceptual development (Carey, 2009; Karmiloff-Smith, 1992). It is particularly intriguing, however, when different behavioral measures such as looking time duration or eye gaze suggest an apparent understanding of the same construct (Butler, Berthier, & Clifton, 2002; Clements & Perner, 1994; Heine et al., 2010; Onishi & Baillargeon, 2005). For example, research on children's theory of mind using verbal response measures suggests that the ability to attribute false belief to others does not reliably appear until around 4 years of age (Wellman & Liu, 2004). However, recent experiments measuring looking time suggest that infants and young toddlers look longer at situations in which observed behavior violates an actor's false belief, indicating that they registered the inconsistency (Baillargeon, Scott, & He,

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0885-2014/$ – see front matter © 2012 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.cogdev.2012.06.001

2010; Onishi & Baillargeon, 2005). Similarly, tasks within the physical domain have shown this pattern, including tests of object permanence (Ahmed & Ruffman, 1998; Baillargeon, 1987). Particularly relevant to the present study, looking time measures in infants (Spelke, Breinlinger, Macomber, & Jacobson, 1992) and children (Hood, Cole-Davies, & Dias, 2003; Mash, Novak, Berthier, & Keen, 2006) suggest an understanding of the relation between solidity and continuity of motion, yet children's reaching behavior is characterized by guesswork or reliance on biases (Hood, Carey, & Prasada, 2000).

Similar evidence exists in studies that use eye gaze measurements of precise points of focus instead of more general looking duration to an entire display. Again, most research on the interplay between gaze direction and verbal/pointing responses is in the social cognitive domain. In a false-belief task, for example, 2.5-year-olds (Southgate, Senju, & Csibra, 2007) and 3-year-olds (Clements & Perner, 1994; Ruffman, Garnham, Import, & Connolly, 2001) often correctly gaze toward the location where an actor will mistakenly look for a desired object, even though their pointing and verbal responses are erroneously directed toward the location where the object actually is. (See He, Bolz, & Baillargeon, 2012, for discussion of task demands.) A recent study tapping competence within the physical domain (Heine et al., 2010) has shown similar results; eye movements in children 6–9 years of age suggested the presence of a more mature, linear model of numerical magnitude while marker placement was based on a less accurate, logarithmic estimation model.

One theory as to why these dissociations occur is that the elicited responses that some tasks depend on (e.g., verbally responding to experimenter-posed questions) pose challenges—above and beyond the actual formation of the representation—that overwhelm very young children's limited cognitive resources. Spontaneous measures such as looking time duration and eye gaze do not pose these challenges, allowing the underlying representational abilities to be manifested in measurable behavior (Baillargeon et al., 2010; He, Bolz, & Baillargeon, 2011). These dissociations have also inspired models of representational change in infants and children, focusing on the process by which information seemingly inaccessible to consciousness—yet capable of guiding behaviors such as eye movements—becomes knowledge available for more active, elicited behaviors (Dienes & Perner, 1999; Karmiloff-Smith, 1992; Munakata, 1997). Yet no consensus exists regarding the characteristics of these early representations or their underlying developmental mechanisms.

The present study aims to provide a piece for this puzzle by examining eye gaze behavior and pointing behaviors outside of the domain of social reasoning. We specifically focus on gaze behavior instead of general looking duration since the latter measures how infants respond after the fact (i.e., postdiction; Meltzoff & Moore, 1998). Looking time thus detects infants' post hoc judgments of consistency/inconsistency and does not necessarily indicate a prediction of the likely end state of an event (Hood et al., 2000; Keen, 2003). In contrast, tasks in which children's eye gaze prior to the end state is measured and tasks in which children are required to respond using verbal/reaching behavior share the common element of prediction. Further, the present task was designed to allow a glimpse of the interplay between eye gaze behavior and underlying, early existing biases, or rules, when task complexity is gradually increased.

We used a "tubes task" of the type used originally by Hood (1995). In Hood's work, 24-month-olds observed a ball as it was dropped down an S-curved opaque tube (either presented singly or with 1–2 other tubes) and slid into a cup. Of interest was the particular cup, of a possible three, that children would search to obtain the ball. Although this task seems relatively simple (to find the ball one should follow the path of the relevant tube), young children frequently erred. The errors, however, were nonrandom; children searched directly beneath the point at which the ball was dropped, evidencing what was termed a "gravity bias". Successful performance on this task (requiring recognition that occluded, curved object trajectories are determined by the dynamic relationship between gravity *and* solidity) was related to number of tubes present and the age of the child. Younger children may correctly search for the ball in a one-tube task, but fail a two-tube task or three-tube task, searching in the cup directly below the drop point. Older children may pass the one- and two-tube task, but not the three-tube task. Thus, success in a simpler task does not guarantee success in a more complex one.

We manipulated task difficulty (one-tube or two-tube) and examined whether children who failed a version of the task in their pointing behavior would demonstrate some knowledge in their eye gaze behavior. We also examined whether eye gaze and/or pointing might be driven by knowledge based on pre-existing, potentially dominant rules (e.g., the “gravity-biased” rule that has been detected in the tubes task and leads to incorrect responses), versus accurate representation of object motion.

2. Method

2.1. Participants

Participants were 21 2-year-olds (11 female; mean age 26 months 28 days, range 24 months 3 days to 30 months 1 day) from primarily middle-class families recruited through birth announcements and free community events in a mid-sized Canadian city. We studied 26-month-olds because they are beginning to overcome the gravity bias on the one-tube, but not the two-tube, task (Hood, 1995). An additional 46 children were excluded because of experimenter error (2), sibling interference (1), refusal to participate after familiarization (6), or insufficient eye-tracking data (37). Within the group of children with insufficient eye-gaze data, three could not be calibrated. The remaining children were calibrated but were excluded from the final analysis because no eye-gaze data was recorded due to a computer error (13), they did not fixate on the hand during the ball drop on enough trials to meet criteria (4), or detection of eye gaze was not stable (sporadic) for any test trials (17). The proportion of excluded participants was comparable to other studies of this age group that used complex eye-tracking procedures (Kloos, Haddad, & Keen, 2006; Southgate et al., 2007). Children from the excluded group did not differ in age or gender from the included group, and their pointing behavior in the one- and two-tube tasks was comparable to that of the included group.

2.2. Apparatus

A small plexiglass frame (40 cm high, 30 cm wide, 10 cm deep) was constructed with three openings on the top and bottom platforms (Fig. 1; based on Hood, 1995). The openings were spaced at 13 cm intervals. Opaque flexible tubes (5 cm wide and 55 cm long) were used to create a pathway between the top and bottom openings. The tube maintained its connection by friction. Three different colored cups were attached to each of the bottom openings and marked A, B, or C.

2.3. Familiarization

Following Hood (1998), children were first familiarized with the different components of the apparatus. An experimenter (E) demonstrated that the opaque tube (at this point separate from the platforms) was hollow by releasing a small ball through the tube held at a 45° incline. This was repeated three times. Next, E familiarized children with the three openings at the top of the apparatus and allowed children to pull out each of the colored cups at the bottom. E placed a ball into each of the cups one at a time, and children were encouraged to retrieve it.

Next, E told children it was time to play a guessing game. First, E demonstrated attaching a tube to one of the openings at the top and a non-aligned cup at the bottom. Children were encouraged to search for the ball after it had been dropped down the tube. They were not given feedback on their choices, nor were they corrected if they searched in the cup directly below the release point (hereafter, Gravity cup) or the cup that was neither directly below the release point nor correct (hereafter, Wrong cup). However, E retrieved the ball from its hidden location if the child could not find it. This was repeated three times or until the child searched in any one of the three cups over three trials when prompted. Learning effects have not been found in this task; that is, children continue to make gravity errors regardless of being shown the correct location of the fallen ball during familiarization (Hood, 1995, 1998).

2.4. Stimuli

Children were presented with 12 video trials consisting of 6 one-tube configurations (one-tube task) followed by 6 two-tube configurations (two-tube task). In each video, a hand appeared from the top right of the screen, reached across the top of the apparatus, stopped above one of the three

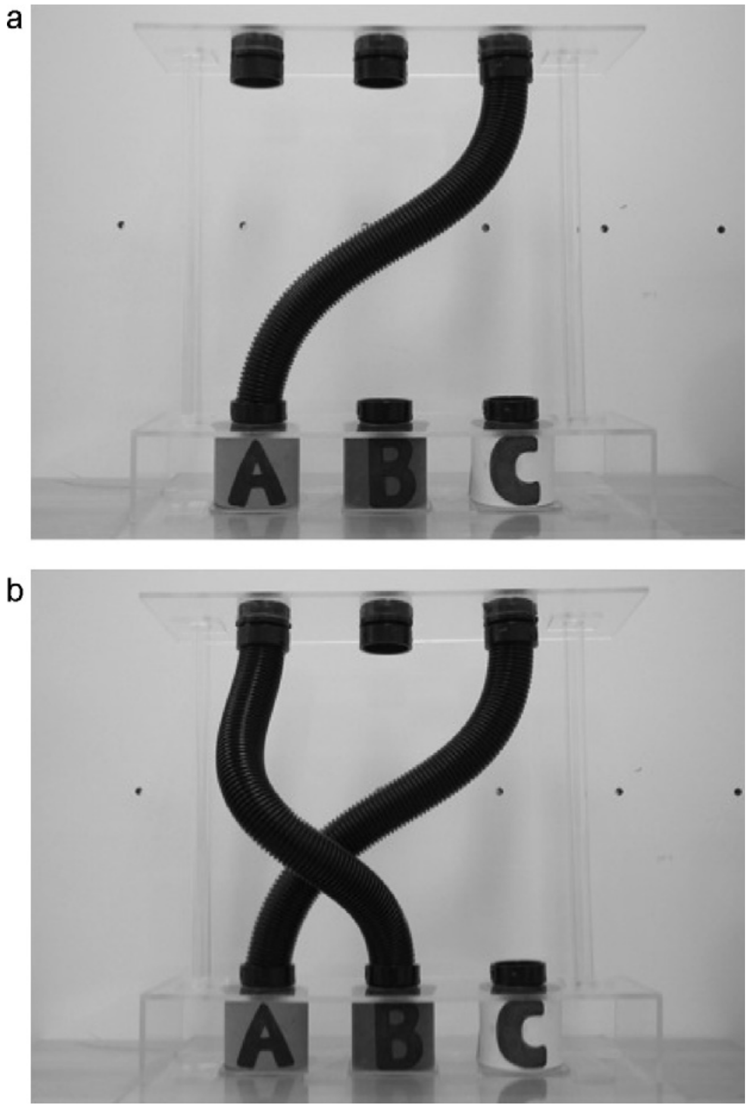

Fig. 1. One of the configurations for the (a) one-tube task and (b) two-tube task.

openings, and dropped a ball down the tube. Following the drop, the hand withdrew and exited the scene from its point of origin. This sequence took approximately 3000 ms and was standardized across all 12 videos. Configurations were counterbalanced such that children never saw a ball dropped down the same opening consecutively. Children were never shown the same configuration twice, nor were they shown a direct, vertical tube arrangement. Two-tube configurations included four crossed and two parallel examples.

2.5. *Test*

An integrated Tobii 1750 near-infrared eye tracker was used to collect and record eye gaze. The eye tracker was integrated into a 17-in. TFT monitor that presented the videos. Image processing software (Tobii Clearview 2.5.1) recorded the gaze from both eyes to the stimuli presentation with a precision of 1°, 0.5° accuracy, and a sampling rate of 50 Hz. During the experiment, each child was seated in a high chair, 30 cm from the monitor. After a five-point calibration was completed, the experiment began. (For technical details about the calibration procedure, see von Hofsten, Dahlstrom, & Fredrikson, 2005.)

Children were told that they were going to play the same guessing game as before but now the game would be on the TV.[1] Following a 2000 ms delay after each drop, children were asked which cup contained the ball ("Where is the ball?"), and their pointing responses were recorded. (Some children provided a verbal response but were prompted to also "show" the answer by pointing.) No feedback was provided, but children received neutral praise following an answer ("good pointing!" or "good work").

2.6. Scoring

Children's pointing responses were recorded on video and coded by two experimenters who were blind to the experimental hypotheses. Their inter-rater reliability was 100%. Because we sought to identify the child's first choice, we coded the first cup the child indicated (by pointing) as the location of the hidden ball after the ball had been dropped. All children provided either a pointing or pointing and verbal response.

Children's gaze behavior was analyzed using the gaze replay file, generated by the image processing software, which included the location of the child's eye-gaze overlaid on the video the child watched during test. Using Adobe Premiere Pro, a frame-by-frame analysis was conducted on the gaze replay files exported from the software. The areas of interest (AOI's) were defined as the three cups. A blind coder identified the child's first saccade to a cup AOI within 1000 ms after the ball was dropped but before the experimenter asked the question at 2000 ms. A saccade was used only if the child fixated on the hand during the dropping action; a fixation was defined as a stable gaze on the hand for at least 2000 ms before the ball was dropped (Engel, Anderson, & Soechting, 1999; Gredeback, Ornkloo, & von Hofsten, 2006), indicating that the child did watch the dropping event and also providing the coders with a point of origin for the saccade. If the child did not fixate on the hand during the dropping action or if there was no saccade within 1000 ms after a fixation on the hand, the trial was excluded. Children having less than 4 trials with eye gaze data that met these criteria were excluded from analyses. A second blind coder coded children's gaze pattern; the two coders agreed on 98.1% of the trials (Cohen's kappa = 0.84). Procedures for analyzing gaze data were similar to those used in other studies of eye-gaze responses to dynamic stimuli (Gredebäck & Melinder, 2010; Southgate et al., 2007).

Each child's performance was calculated as the number of first points or first eye movements toward a Correct, Gravity, or Wrong cup, divided by the number of total trials completed for each tube task. A Correct response was defined as correctly indicating the location of the fallen ball. A Gravity response was defined as indicating the location directly below where the ball was dropped, and a Wrong response as indicating the cup that was neither the correct nor gravity location.

3. Results

Children were divided into two groups based on their passing the one-tube task, as indicated by their pointing or pointing and verbal responses. The No-Pass group ($n = 13$, mean age = 26.59 months, SD = 1.91, male = 7) did not perform above a chance level on the one-tube task.[2] The One-Tube-Pass group ($n = 8$, mean age = 27.37 months, SD = 0.86, male = 3) performed at an above-chance level. The two groups did not differ significantly in age, $F(1,19) = 1.15$, $p = 0.29$.

3.1. Preliminary analyses

A series of preliminary analyses of variance (ANOVAs) was conducted with gender and age as between subjects variables and proportion of trials with correct predictive gaze or search and

[1] Hood (1998) used a similar familiarization and computer screen. Children still reliably made the gravity error.

[2] The probability of choosing the correct cup on the first trial by chance was 0.33. A binomial distribution was used to determine the number of trials out of the total number of completed trials a child would require to perform significantly above chance. With a one-tailed rejection region of 0.05, we determined that children who completed 6 test trials must find the ball on 5 or more trials to be categorized as showing above-chance correctness. Children who completed 5 test trials had to find the ball in 4 or more trials to perform above chance.

proportion of trials with gravity predictive gaze or search as dependent variables. There were no significant main effects or interaction effects (all $p > 0.05$), so subsequent analyses were collapsed across gender and age.

The mean number of trials considered for analysis in each task was 5.4 (S.D = 0.59, range = 4–6) for the one-tube task and 5.0 (S.D = 0.78, range = 4–6) for the two-tube task. All children except two completed a minimum of 5 trials on each task and most persisted for the full 6. On the one-tube task, mean number of trials completed was 5.3 for the No-Pass group and 5.6 for the One-Tube-Pass group. Mean number of trials completed on the two-tube task was 5.08 for the No-Pass group and 5.1 for the One-Tube-Pass group). These means did not differ significantly for either task.

3.2. *One-tube task*

3.2.1. *Gaze patterns*

The No-Pass group looked to the Correct cup first on 64.4% of the trials, a proportion significantly higher than looks to the Gravity cup (35.5%, $t(12) = 2.90$, $p < 0.01$) or the Wrong cup (1.28%, $t(12) = 11.13$, $p < 0.01$). Similarly, the One-Tube-Pass group looked to the Correct cup on 77.5% of the trials, a significantly higher proportion than looks to the Gravity cup (22.5%, $t(7) = 2.92$, $p < 0.02$) or the Wrong cup (0%). There was no difference across groups in looks to the Correct cup, $F(1,19) = 1.73$, $p = 0.20$, to the Gravity cup, $F(1,19) = 1.65$, $p = 0.21$), or to the Wrong cup, $F(1,19) = 0.60$, $p = 0.44$ (Fig. 2a).

3.2.2. *Pointing patterns*

The No-Pass group pointed to the Gravity cup on 59.1% of trials, slightly more than points to the Correct cup (36.5%) of trials. This difference was marginally significant, $t(12) = 5.47$, $p < 0.06$. This group pointed significantly more to the Gravity cup than to the Wrong cup (4.3%, $t(12) = -1.84$, $p < 0.01$) (Fig. 2b). In contrast, the One-Tube Pass group pointed more to the Correct cup (90.8%) than to the Gravity cup (7.08%, $t(7) = 12.58$, $p < 0.01$), or to the Wrong cup (2.0%, $t(7) = 19.33$, $p < 0.01$). Group comparison confirmed that the One-Tube-Pass group was more likely to point to the Correct cup than the No-Pass group, $F(1,19) = 52.08$, $p < 0.01$, and the No-Pass group to the Gravity cup than the One-Tube-Pass group, $F(1,19) = 44.17$, $p < 0.01$.

3.2.3. *Pointing patterns in relation to gaze patterns*

To further examine the relation between gaze and point behavior, analyses were conducted on children's point responses following a look to the Correct cup. For the No-Pass group, a look to the Correct cup was just as likely to be followed by a point to the Correct cup (50%) as the Gravity cup (50%). In contrast, for the One-Tube-Pass group a look to the Correct cup was most likely followed by a point to the Correct cup (97%), rather than the Gravity cup (2%). Neither group pointed to the Wrong cup following a look to the Correct cup.

3.3. *Two-tube task*

No significant differences appeared between the One-Tube-Pass group and the No-Pass group in performance on the two-tube task. Thus the groups were combined for analysis. Using the same criteria as in the one-tube task, no child passed the two-tube task, judged by pointing responses.

3.3.1. *Gaze patterns*

No child looked to the Wrong cup. More children looked to the Gravity cup than the Correct cup (59.3% vs. 40.3%, $t(20) = 2.10$, $p < 0.05$). Of 21 children, 13 looked more to the Gravity cup (significantly above chance[2]), 5 looked to the two cups equally, and 3 looked to the Correct cup.

3.3.2. *Pointing patterns*

Children made significantly more points to the Gravity cup than to the Correct cup (64.3% vs. 25.5%, $t(20) = 3.46$ $p < 0.01$)or to the Wrong cup (10.2%, $t(20) = 6.30$, $p < 0.01$). Of 21 children, 16 pointed to the Gravity cup (significantly above chance[2]) on a majority of trials, while 5 pointed more often to the

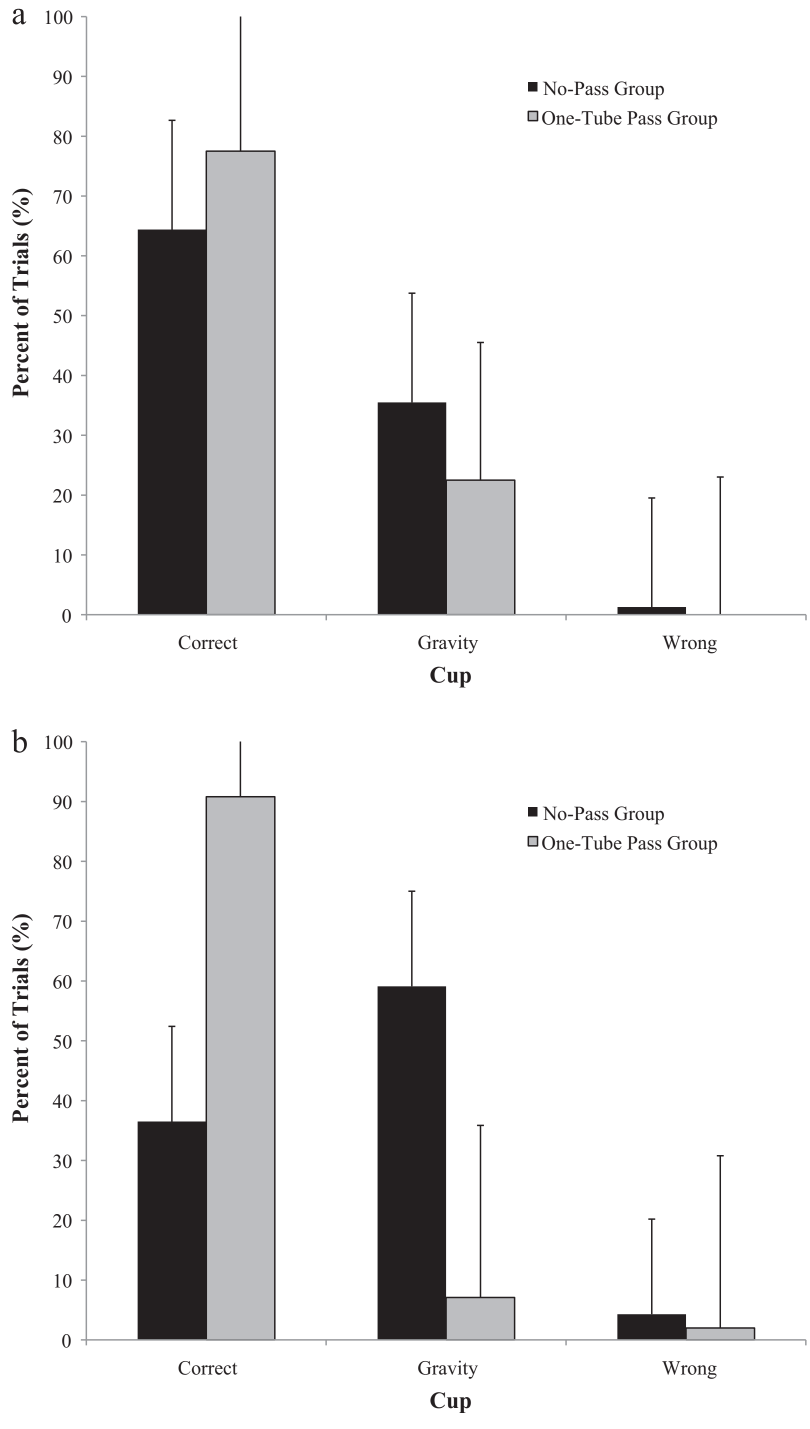

Fig. 2. (a) Mean eye gaze performance of No-Pass and One-Tube-Pass groups on the one-tube task. (b) Mean pointing performance of No-Pass and One-Tube-Pass groups on the one-tube task. Error bars depict standard error.

Correct cup. It should be noted that these pointing and gaze patterns occurred for trials in which a tube was attached or not attached to the gravity cup.

3.3.3. Pointing patterns in relation to gaze patterns

A look to the Gravity cup was followed by pointing to the Gravity cup on 51% of trials, the Correct cup on 15.8%, and the Wrong cup on 7.8% of trials. A look to the Correct cup was also followed by a point to the Gravity cup (58.9%) more often than the Correct cup (33.0%) or the Wrong cup (5.1%).

4. Discussion

We investigated whether there were differences in eye gaze patterns by 26-month-olds who succeeded or failed to point to correct locations in two variants (one-tube and two-tube) of a task designed to examine young children's ability to track and occluded object moving on a curved path vis-à-vis the constraints of gravity an solidity. Specifically, we were interested in measuring eye-gaze patterns and pointing behavior to provide insight into a growing literature examining representational development.

The findings regarding pointing behavior are consistent with previous findings (Hood, 1995, 1998) that children who erred did so in a nonrandom manner. That is, they pointed at a location straight down from the release point of a ball, even though the tube that the ball traveled in detoured to one side (a "gravity bias"). Also consistent with Hood's (1995) findings, success on the one-tube task did not guarantee success on the two-tube task, suggesting that understanding develops gradually; incorporation of the constraints of gravity and solidity in spatiotemporal tracking that allows for trajectory representation in a simple case does not directly transfer to understanding in a slightly more complex case. Instead, in the two-tube task, children previously successful on the one-tube task showed the gravity bias.

The tubes task provides an opportunity to examine the interplay between eye gaze behavior and pointing behavior outside of the domain of social reasoning and to examine the interplay between eye gaze behavior and underlying biases and rules while incrementally increasing task complexity. Results showed that some children who failed the one-tube task by pointing to the Gravity cup nevertheless looked to the correct location of the dropped ball, just like those who pointed correctly. Thus, one form of behavior (eye gaze) is directed to a correct response while another (pointing) is apparently guided by a seemingly powerful bias or rule (that objects always fall straight down). However, children favored the Gravity cup in both eye gaze and pointing responses in the two-tube task.

The present results fit into a growing body of research documenting the apparent dissociation between eye gaze and action behavior (Baillargeon et al., 2010; Clements & Perner, 1994; Clements, Rustin, & McCallum, 2000; Dienes & Perner, 1999; Heine et al., 2010). How might we best characterize the forms of representation that guide the eye gaze behavior and pointing in the present task? Many theoretical approaches fit with the current findings, and the present study does not allow us to choose definitively among them. We can, however, identify consistencies and remaining questions in relation to these models.

According to one class of theoretical models, the dissociation between eye gaze and pointing/verbal behavior may be caused by differences in processing load, not differences in the actual underlying representation of the event (He et al., 2011; Surian & Geraci, 2011). A distinction is made between 'spontaneous-response' tasks, such as measures of looking-time or eye-gaze, and 'elicited-response' tasks, in which children answer a direct question about their knowledge of a particular event. It is proposed that the latter demands more processing resources as not only must a representation be made (similar to the spontaneous-response tasks), but previous knowledge must be inhibited and response selection enacted. Thus, in the present study, children may have pointed to the Gravity cup after the prompt because the cognitive demands of holding a representation of the occluded ball, producing an answer, and inhibiting their gravity bias was overwhelming. In contrast, children spontaneously looked at the Correct cup prior to a prompt since this behavior required only two of the three demands – representation of the ball's location and inhibition of the gravity bias.

Other models propose that dissociations reflect representational change. Clements and Perner (1994) found that 3- and 4-year-olds who gave incorrect verbal responses regarding where an actor would look for a desired object in a false belief task looked in anticipation at the correct location. Slightly younger children (2.5 years), however, did not provide a correct verbal response or look to the correct location. They suggested that present at 3 years is an implicit understanding of belief, or a "knowledge which is unverbalizable" (p. 391, 1994). Furthermore, the implicit knowledge manifested by anticipatory eye gaze likely reflects an abstraction of a learned behavioral regularity regarding the fact that people look for items the last place they put/saw them (Clements et al., 2000; Perner & Clements, 1998; Southgate et al., 2007). The proposal that eye gaze behavior on false belief tasks implies implicit knowledge stemming from observed behavioral regularities, however, does not apply perfectly to the present study. In the tubes task, the presumed ‘regularity’ held by children is that dropped objects travel straight down (gravity bias) which would lead to *incorrect* eye gaze, the opposite pattern to our results. One would have to posit that the correct eye gaze behavior found here reflects a newly achieved abstraction of object motion regularities in relation to gravity and solidity (e.g., via observation of motion paths on slides, etc.).

Karmiloff-Smith (1992) has also presented a seminal model regarding the implicit/explicit knowledge distinction, although in her model implicit knowledge (I) is procedural in nature and is then redescribed at an abstract, explicit level (E1, then E2 and E3). It is possible that the eye gaze behavior observed in the present study reflects implicit procedural knowledge, although this would require that children routinely witnessed, and repeatedly anticipated, obscured objects falling based on gravity—and its interplay with solidity—and connected this to the novel tubes apparatus they encountered in the laboratory, which seemingly goes beyond the scope of the I-level. Further complicating the application of this model to the present findings is that the gravity bias implies that if there *is* procedurally based implicit knowledge reflected in the tubes procedure, it would result in looking behavior toward the location directly below the dropping point, not the correct location. One possibility is that gravity based choices reflect I-level knowledge which is then coupled with I-level knowledge in other microdomains (e.g., solidity) to allow for the eye behavior observed here, which would then be considered E1-level knowledge. Note that this possibility fits the spirit of Karmiloff-Smith’s model since “although E1 representations are available as data to the system, they are not necessarily available to conscious access and verbal report” (p. 22, 1992). Furthermore, Karmiloff-Smith proposes that these representations are not general stages (there are no “phase E1 children”), and knowledge does not necessarily transfer when evaluating more complex stimuli. This may explain why children could pass the one-tube task, but fail to show correct eye gaze on the similar but more complex two-tube task.

Incorrect, gravity-biased pointing and correct eye gaze may also be thought of as the coexistence of two types of search strategies, overlapping for a period of development (Siegler, 1996). The strategies may be predicated by knowledge types that map onto the implicit/explicit distinction or perhaps as the result of a ‘weak’ representation (Munakata, 1997) that is sufficient to guide gaze but insufficient to overcome gravity-biased representations and guide pointing. Central to these ideas would be the role of inhibitory control, as well as the assumption that it would be somehow easier to inhibit gravity-biased eye gaze than gravity-biased pointing. It remains unknown why one behavior might overcome the gravity bias more easily than the other, though possibilities include the declarative nature of the pointing response versus the orienting basis of eye gaze.

Many fundamental questions remain as to how to characterize the knowledge that can guide eye gaze behavior and the knowledge that can guide verbal or pointing behavior, and why there might be a developmental difference between them. Study of a group of slightly older children could determine whether correct gaze behavior on the two-tube task occurs prior to correct pointing behavior—mirroring the pattern seen with the one-tube task—which in turn would speak to questions regarding the availability of knowledge transfer to new scenarios. Additionally, examining infants’ looking duration to outcomes in which the ball appears in the correct location versus the gravity location would be telling, as would gaze coding via an eye tracker similar to that used in the present study. Together, such studies would build upon the present findings to further elucidate the type of knowledge each behavioral measure reflects.

Acknowledgement

This work was supported in part by a grant from the Natural Sciences and Engineering Research Council of Canada to V. Kuhlmeier.

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