Infant Behavior & Development 45 (2016) 64–70

Contents lists available at ScienceDirect

Infant Behavior and Development

Seeing double: 5-month-olds' mental rotation of dynamic, 3D block stimuli presented on dual monitors

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ARTICLE INFO

Article history:
Received 29 February 2016
Received in revised form 7 September 2016
Accepted 22 September 2016
Available online 12 October 2016

Keywords:
Mental rotation
Infant development
Spatial cognition

ABSTRACT

Mental rotation (MR) involves the ability to predict how an object will look once it has been rotated into a new orientation in space. To date, studies of MR in infants have tested this ability using abstract stimuli presented using a single display. Evidence from existing studies suggests that using multiple displays may affect an infant's performance in some kinds of MR tasks. This study used Moore & Johnson's (2008) simplified Shepard-Metzler objects in a dual-monitor MR task presented to five-month-old infants. Evidence for MR in infancy was found. These findings have implications for MR testing in infancy and the influence of display properties on infant MR performance.

Mental rotation (MR) involves the ability to predict how an object will look once it has been rotated into a new orientation in space. In studies of the development of this cognitive ability, evidence for MR has been reported as early as three months of age (e.g. Hespos & Rochat, 1997; Moore & Johnson, 2011; Quinn & Liben, 2008, 2014). With verbal populations, MR is traditionally tested using tasks that measure reaction times and error rates in order to assess how well individuals match objects that differ in their spatial orientations. This matching task involves a multi-step cognitive process including perceptual and decision making components (Parsons, 2003). To assess MR abilities in infants, researchers conduct behavioral studies that track visual fixation and measure looking times. These studies usually assess the discrimination of stimuli by looking at infant novelty preferences following habituation.

Infants *habituate* to repeatedly presented stimuli – that is, their looking times decline with repeated stimulus presentations (Flom & Pick, 2012; Kavsek, 2012; Sirois & Mareschal, 2004) – and in subsequent test trials, novel stimuli typically attract longer looking times than do the previously viewed stimuli. Thus, one of the methodologies used to assess MR in infants involves first presenting an object repeatedly rotating through an angle less than 360° until the infants have habituated to the stimulus (i.e., their looking times have declined). In a series of subsequent test trials, an infant is shown the original stimulus object from a new perspective (i.e., rotating through the remaining degrees in the rotation) as well as a novel stimulus; the novel stimulus is the mirror image of the other test display. For infants habituated to the initial presentation, longer looking times at the mirror image stimulus suggest that MR has occurred, because such a novelty preference implies that the infant *recognizes* (and is still bored by) the familiar object rotating through the new angle. Moore and Johnson (2008) employed this approach to assess MR abilities and found sex differences in 5-month-old infants; males preferred

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http://dx.doi.org/10.1016/j.infbeh.2016.09.005
0163-6383/

(i.e., spent more time looking at) the novel stimulus, whereas females split their looking times equally between the familiar object shown from a new perspective and the mirror image of that display.

More recently, Moore and Johnson (2011) utilized the habituation approach to examine MR abilities in 3-month-old infants. Consistent with previous research, females spent the same amount of time fixating the familiar and novel test stimuli, suggesting that discrimination between these objects did not occur. However, males looked significantly more at the *familiar* test object. This finding is not consistent with the previously observed behavior of 5-month-old males, raising important questions about the familiarity preference at 3 months of age. Based on a model designed to predict infant familiarity versus novelty preferences, Hunter, Ames, and Koopman (1983) proposed that factors such as familiarization time, infant age, and stimulus complexity influence infants' looking times. Several studies have shown that younger infants who do not reach a criterion for habituation may continue to prefer fixating familiar objects, presumably in an attempt to gather more information about the stimulus (Colombo, 1995; Roder, Bushnell, & Sasseville, 2000). Thus, processing time involved in encoding and retaining an object in memory may influence infants' looking times. Specifically, the familiarity preference reported by Moore and Johnson (2011) may indicate that MR occurred, but that younger infants had more difficulty processing the three-dimensional (3D) block stimuli than did older infants.

A review of existing research on MR in infancy suggests that the age of the participant as well as stimuli used for the task (e.g., Lauer, Udelson, Jeon, & Lourenco, 2015; Moore & Johnson, 2008, 2011; Quinn & Liben, 2014) may affect task performance, and thereby influence whether novelty or familiarity preferences are produced. Thus, it may be important to consider stimulus and display components of MR tasks with infants when trying to understand the early development of MR abilities. Existing evidence suggests that designs in which stimuli are presented in pairs (i.e., on two different monitor displays) may reduce demand on visual short-term memory and increase the number of glances between the test stimuli, thereby allowing infants to encode more detail about stimuli differences than they can in a design using a single monitor display (Oakes & Ribar, 2005).

Oakes and Ribar (2005) presented 4- and 6-month-olds with photographs of a collection of dogs (or cats) during six 15-s familiarization trials followed by two 10-s test trials in which a novel within-category photograph (i.e., a dog) and a novel item from the contrasting category (i.e., a cat) were presented. The familiarization and test photographs were presented successively on one computer monitor or side-by-side on two computer monitors. Six-month-old infants discriminated between the different categories of animals in both conditions, however 4-month-olds preferred the novel item only when the stimuli were presented side-by-side on two computer monitors. Oakes and Ribar concluded that features of discrimination tasks may be particularly important for categorical discrimination in infants younger than 6 months.

Since then, two labs have used side-by-side presentations of two-dimensional (2D) stimuli and found evidence for MR in infants as young as 3 months. Quinn and Liben (2008, 2014) tested 3- to 4-month-olds, 6- to 7-month-olds, and 9- to 10-month-olds by presenting them with two side-by-side presentations of the number "1" or its mirror image in seven different static rotations; these familiarization trials were followed by two test trials in which the original stimulus object was seen from a mirrored *and* a new perspective, simultaneously. Male but not female infants preferred looking at the novel stimulus (mirror image) in all of their experiments assessing MR. Similarly, Lauer et al. (2015) presented older infants with side-by-side Tetris-like figures on the right and left sides of one screen and found that 6- to 13-month-old infants preferred the novel stimulus. Compared to Lauer and colleagues' female infants, their male infants spent more time looking at the novel versus the familiar stimulus, but both the male and female infants preferred the novel stimulus over the familiar stimulus. Thus, stimulus type as well as display features may influence infant performance in MR tasks.

The current study assessed the influence of display type on MR performance in a population of 5-month-old infants, using a variation of the method described by Moore and Johnson (2008, 2011). Specifically, a dual monitor set-up was used instead of a single monitor set-up. In the habituation trials, identical stimuli were presented simultaneously on two side-by-side monitors; these stimuli were video representations of 3D, simplified Shepard-Metzler block objects. After habituation, infants saw two different test stimuli at once, rather than seeing the two test stimuli alternate on one monitor as in Moore and Johnson (2008, 2011). Although the single-monitor studies that have been published to date have found evidence for MR in male infants only (Moore & Johnson, 2008, 2011), we expected the use of the dual monitor set-up to facilitate all infants' performances in this MR task, allowing female as well as male infants to provide evidence of MR.

1. Method

1.1. Participants

New parents in the San Gabriel Valley of Southern California were contacted by mail, and interested parents returned a postcard or contacted us via the Internet to indicate their desire to participate in the study. The final sample consisted of 24 male and 24 female healthy, full-term 5-month-old infants who were tested by a trained observer (*M* age = 152.50 days, *SD* = 6.84 days; males: *M* age = 152.67 days, *SD* = 7.21 days; females: *M* age = 152.33 days; *SD* = 6.61 days). Fourteen additional infants were tested but excluded from analysis; this group included 7 girls (out of 31 tested) and 7 boys (out of 31 tested), so males and females were excluded in similar proportions. Infants were excluded due to observer error ($n = 1$), a mother opting out in the middle of testing ($n = 1$), technical malfunction ($n = 3$), fussiness ($n = 4$), or insufficient attention to the experimental stimuli ($n = 5$). The observer determined if each infant displayed fussiness (e.g. crying, or appearing uncomfortable or irritable) or an insufficient amount of attention to the experimental stimuli (i.e., looking primarily away from the stimuli, sometimes

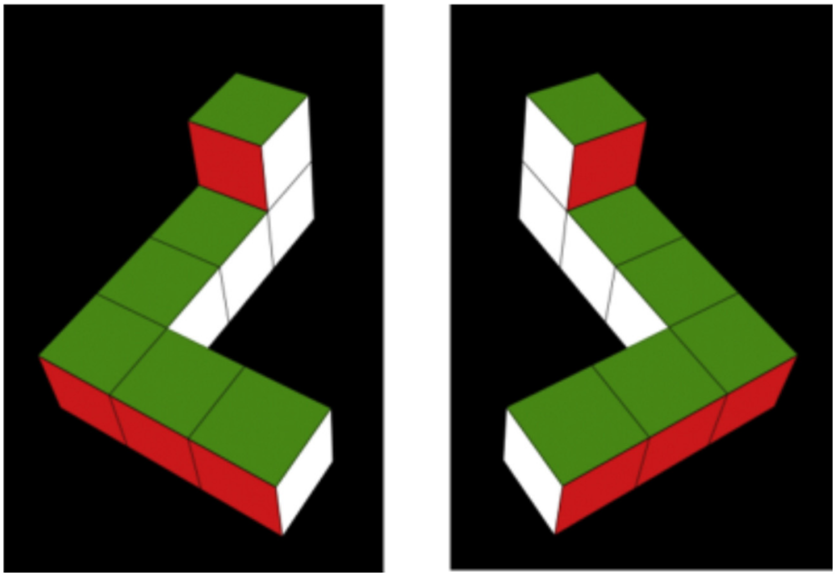

Fig. 1. 3D Shepard-Metzler object (Shepard & Metzler, 1971), arbitrarily called the L-object, and its mirror image, the R-object, pictured on the left and right, respectively.

at the ceiling or at their own toes, for example). Although this decision was subjective, the observer was blind to the infant's assigned condition, and the determination to exclude the data was made *before* looking at the data, so these exclusions could not have affected the experimental outcomes.

1.2. Stimuli

The stimuli were a set of 4 videos depicting representations of 3D, simplified Shepard-Metzler geometric block objects developed by Moore and Johnson (2008). All stimuli were presented on a black background and rotated as described in Moore and Johnson (2008, 2011). The object shown in one habituation and one test video was referred to as the "L-object" and the object portrayed in the other two videos (one habituation and one test) was referred to as the "R-object" (see Fig. 1). Each stimulus object was constructed of seven cubes attached rigidly with 90° bends at its top and bottom; a two-cube bar (x-axis) was attached at the bottom of a straight central bar formed of four cubes (y-axis), and a single cube bar (z-axis) was attached to the top of this central bar. If viewed from above, all visible faces of the objects were yellow; if viewed from below, all visible faces were red. Viewed from the front, right, back, and left, the faces were purple, blue, white, and green, respectively. The L- and R-objects were mirror images of one another.

Each habituation video was composed of 160 sequential perspective projections. Each of these projections represented the same object rotated an additional 1.5° around the vertical axis. When presented at 30 frames per second, this series of images appeared as an object rotating at 45° per second through a 240° arc. On reaching its maximum extent of rotation, the object appeared to reverse course, rotating back to its starting point. As in Moore and Johnson (2008), the test videos of the L- and R-objects continued the rotation of the L- and R-objects in the habituation videos, respectively, through the previously unseen 120° of arc. Each of the 80 frames constituting a test video represented the habituation object rotating an additional 1.5° around the vertical axis. Thus, a habituation video and its corresponding test video together represented a complete 360° turn of the object around the vertical axis. Like the objects in the habituation videos, the objects in the test videos continuously rotated back and forth between their starting points and the maximum extents of their rotations. Other than being mirror images of one another, the L- and R-test stimuli were identical in all respects, and no still frame of either habituation stimulus was identical to any still frame of either test stimulus.

1.3. Apparatus & procedure

The observer described the study procedure to volunteer parents who completed informed consent forms and an infant questionnaire. If two parents attended the testing session, one was instructed to sit in the lab's waiting area, where they were able to view their infant and partner on a closed-circuit television screen during the procedure. Infants were tested sitting on their parent's lap in a darkened testing room, one meter from two 53 cm monitor screens which were separated by 39 cm (from one monitor edge to the other). Parents were instructed to keep their eyes closed throughout the procedure; all parents whose babies' data were included in the analyses were observed to have complied with this request, so parents were unable to systematically influence their infants' visual preferences. An IBM PC clone running custom software was used to present the stimuli on the monitor, time trials, calculate the habituation criterion, and store data.

One trained observer, invisible to the infant and blind to the infant's group assignment and to the stimuli shown, observed the infant's behavior and used the computer's joystick to initiate trials and record the durations of the infants' fixations. Because of the distance between the display monitors and the distance of the infant from the screens, infants typically move their eyes—and often, their heads—quite a distance when observing stimuli in our 2-monitor testing room. Therefore, it is easy to tell when they are fixating one screen rather than the other, as evidenced by the fact that reliability scores among the trained observers who conduct studies in our laboratory are consistently higher than $r = 0.90$. The specific inter-observer reliability score for the observer who recorded the infants' visual behaviors in this particular task was r = 0.91. This reliability score was obtained by comparing the looking time data recorded simultaneously by the current observer and one other trained observer while three pilot infants were tested in the task.

The trial proceedings were similar to those used by Moore and Johnson (2008, 2011), except that two monitor displays were used. Infants were randomly assigned to the L- or R-habituation group such that in an initial series of identical habituation trials, they saw the same habituation video on both monitors portraying either the rotating L- or the rotating R-object. The use of these two groups effectively controlled for any spontaneous preferences the infants might have had for the stimuli used in these studies. An attention-getter stimulus was used on both monitors before each trial to ensure the infant was attending to the video screens.

Each trial began when the observer pressed a button on the joystick to indicate that the attention-getter stimulus had drawn the infant's attention to one of the monitors. The observer recorded fixations to the left and right monitors using the joystick. Each habituation trial was terminated either 2 s after the observer released the joystick to indicate that the infant was no longer fixating either of the displays, or after 60 s (whichever came first). If the infant returned attention to one of the stimuli in the 2-s interval, the trial continued. Each infant was considered habituated when his/her average time fixating the habituation stimulus (across both monitors) declined in a given four-trial block to 50% of his/her average fixation time in the first four habituation trials. Thus, each infant saw a minimum of five habituation trials.

Once the infant habituated (or after s/he had experienced 12 habituation trials, whichever came first), s/he saw a series of two test trials. Each infant saw the L- and R-test stimuli simultaneously in these two trials; as indicated above, each of these videos presented the stimulus object moving through a previously unseen angle of rotation. Twelve randomly selected infants from each of the two habituation groups saw the L-test stimulus on the left screen in the first test trial, and the other 12 infants in each habituation group saw the R-test stimulus on the left screen in the first test trial. Unlike in the habituation trials during which infants saw an identical object on both monitors, the test trials presented the habituation object (seen from a new perspective) on one monitor, and a novel object (the mirror image of the other stimulus) on the other monitor. Both test stimuli were seen revolving through a 120° angle such that all views were novel relative to the habituation displays. Right-left positions of these stimuli were subsequently reversed for a 2nd test trial. During each of the two test trials, the stimuli remained on the two monitors until infants accumulated a total of 20 s of looking time across both monitors.

2. Results

The principal dependent measure was looking time during the test trials at the novel (i.e., mirror image) geometric block object versus the familiar (i.e., habituated) geometric block object seen from a new perspective. Two *t*-tests were used to assess if habituation group (L- and R-) influenced infant performance. No statistically significant differences were found between the L- ($M = 10.16$, $SD = 2.16$) and R- ($M = 10.18$, $SD = 4.91$) habituation groups in the amount of time that the infants fixated on the stimuli before reaching the habituation criterion, $t(46) = -0.02$, $p = 0.985$, $d = -0.01$. Further, the difference in the number of trials the infants required in the L- ($M = 9.29$, $SD = 2.68$) and R- ($M = 8.75$, $SD = 2.63$) habituation groups to habituate, was not statistically significant, $t(46) = 0.71$, $p = 0.483$, $d = 0.20$.

Two more *t*-tests were used to assess if sex influenced infants' behaviors during the habituation trials. The difference in the amount of time that the male ($M = 147.10$, $SD = 122.86$) and female ($M = 114.19$, $SD = 74.02$) infants fixated on the stimuli before reaching the habituation criterion was not statistically significant, $t(46) = 1.12$, $p = 0.267$, $d = 0.32$. The difference in the number of trials required for the male ($M = 9.00$, $SD = 2.72$) and female ($M = 9.04$, $SD = 2.61$) infants to habituate was not statistically significant $t(46) = -0.05$, $p = 0.957$, $d = -0.02$. Approximately equal numbers of male ($n = 15$) and female ($n = 16$) infants habituated in less than 12 habituation trials, $\chi^2 = 0.09$, $p = 0.763$.

A 2 (stimulus: novel versus familiar) by 2 (sex: female versus male) mixed analysis of variance (ANOVA) was used to analyze the looking times and resulted in a main effect of stimulus. The average looking times at the familiar stimulus across the two test trials were significantly greater ($M = 10.17$; $SD = 3.75$) than the average looking times at the novel stimulus ($M = 8.88$; $SD = 2.28$), $F(1, 46) = 4.44$, $p = 0.041$, *partial* $\eta^2 = 0.01$, reflecting a familiarity preference (See Fig. 2). There was no statistically significant main effect or interaction involving sex, Fs < 0.10. The difference between the male infants' ($M = 10.33$, $SD = 1.92$) and female infants' ($M = 10.00$, $SD = 5.00$) looking times at the familiar stimulus was not statistically significant, $t(46) = 0.30$, $p = 0.767$, $d = 0.09$.

Because a previous study of 5-month-old infants using the same stimuli and procedure reported novelty preferences (Moore & Johnson, 2008), we analyzed for differences in habituation times between this and the previous study. Overall, the difference between the infants' time to habituation in Moore and Johnson's (2008) study ($M = 102.55$, $SD = 61.59$) and the current study ($M = 130.65$, $SD = 101.70$) was not statistically significant, $t(86) = -1.53$, $p = 0.130$, $d = -0.33$. However, on

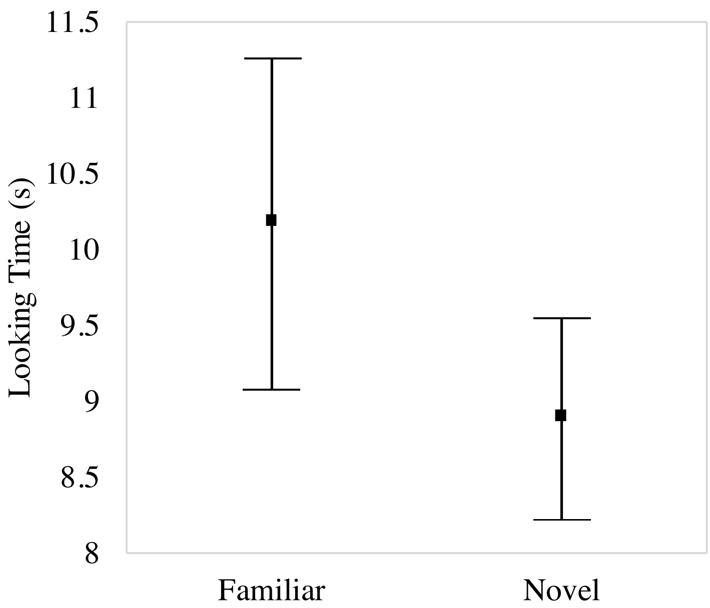

Fig. 2. Means and 95% confidence intervals for average looking time, by stimulus type. The average looking times for the familiar stimulus across the two test trials were greater than those for the novel stimulus, $F(1, 46) = 4.44$, $p < 0.05$, *partial* $\eta^2 = 0.01$, reflecting a familiarity preference.

average, the male infants took less time to habituate in Moore and Johnson's (2008) study ($M = 90.37$, $SD = 54.83$) than did the males in the current study ($M = 147.10$, $SD = 122.86$), $t(42) = -1.91$, $p = 0.05$, $d = -0.58$. In contrast, there was no significant difference between female infants' time to habituate in Moore and Johnson's (2008) study ($M = 114.73$, $SD = 66.84$) and the current study ($M = 114.19$, $SD = 74.02$), $t(42) = 0.03$, $p = 0.980$, $d = 0.01$.

3. Discussion

The current experiment presented video representations of 3D, simplified Shepard-Metzler geometric block objects on a dual monitor display instead of on a single monitor display, and found a significant familiarity preference in 5-month-old infants. This preference implies that infants recognized the habituation stimulus even after it was rotated into a new perspective. Accordingly, the infants recognized the rotated block object as the familiar stimulus and fixated on it, perhaps for further processing. As Moore and Johnson (2011) have argued, this kind of recognition likely involves the rotation of a mental representation (either of the previously seen habituation stimulus or of the visible test stimulus). Therefore, these results are consistent with prior research that reported MR abilities in infants (Moore & Johnson, 2008, 2011; Quinn & Liben, 2008).

Although we observed a significant familiarity preference in this study, some labs (Lauer et al., 2015; Quinn & Liben, 2008, 2014) have reported *novelty* preferences in MR tasks in which two stimuli were displayed simultaneously; thus, the current familiarity effect requires explanation. In these other labs, infants were presented with 2D stimuli that were rotated in sequential static presentations around the x-axis. In contrast, in the current study, infants were presented with 3D stimuli that were dynamically rotated around the y-axis. Although the number of monitor displays used in the current study was consistent with the other labs' designs (Lauer et al., 2015; Quinn & Liben, 2008, 2014), our stimuli were more complex (3D versus 2D) and dynamic (versus static), and under these conditions, infants exhibited a significant preference for the familiar stimulus. Therefore, stimulus complexity might account for these differing results.

Hunter et al. (1983) suggested that post-habituation familiarity effects are likely when infants have not finished processing stimuli seen during habituation. Factors that influence processing time include stimulus complexity, as well as age, familiarization time, and fixation duration (Colombo, 1995; Moore & Johnson, 2011; Roder et al., 2000). So, the finding that two-display methods that use relatively simple stimuli yield novelty effects whereas two-display methods that use relative complex stimuli yield familiarity effects is consistent with Hunter and colleagues' suggestion.

Furthermore, Moore and Johnson (2008) discovered significant novelty preferences in a single-monitor study that used stimuli identical to those used in the current study; in addition, both of these studies tested infants of the same age. If our argument about the role of complexity in producing familiarity versus novelty effects is correct, then the discovery of a familiarity effect in the current study suggests that the dual monitor set-up might have increased rather than decreased the complexity of this task for the infants. Some corroborating evidence that the dual monitor set-up made the task more difficult was revealed in the analysis that showed that male infants in the current study took longer to habituate to the dual-monitor display than did the male infants in Moore and Johnson's (2008) study, who saw the habituation stimuli on a single monitor. Nevertheless, despite this increased difficulty, the 5-month-olds in the current study still provided evidence of MR competence, albeit in the form of a familiarity preference rather than a novelty preference.

Prior research suggested that a dual monitor protocol in which stimuli are presented side-by-side may reduce infant memory load (Oakes & Ribar, 2005). However, the current results suggest that this method may have made the MR task *more* difficult for the infants. The use of two simultaneously presented stimuli may have resulted in infants comparing the two stimuli to one another, thereby decreasing demands on visual short-term memory but increasing demands on attention. Such a response could have slowed down processing of the habituation stimuli, which would explain why the infants ultimately spent more time looking at the familiar stimulus during the test trials (Hunter et al., 1983). The finding that a dual monitor set-up produces familiarity rather than novelty preferences in this MR task informs future studies using this task and provides insight regarding the influence of a particular task factor, namely display type. Nonetheless, the current results add to the growing body of evidence indicating that infants can succeed at some MR tasks by the age of 5 months.

Unlike Moore and Johnson (2008, 2011), the current results do not support a statistically significant sex difference in MR performance. Of course, such null results are not evidence that a sex difference does not exist; in fact, *any* interpretations made from null findings may be misleading (Cumming, 2013). Nonetheless, these null results warrant comment. Although several prior studies reported sex differences in infant MR suggesting that male infants outperform female infants in MR tasks (Lauer et al., 2015; Moore & Johnson, 2008, 2011; Quinn & Liben, 2008, 2014), others have not reported significant sex differences (e.g., Schwarzer, Freitag, Buckel, & Lofruthe, 2013; Slone, Moore, & Johnson, 2016).

Interestingly, some studies using stimuli and methods like those used in the current study and in Moore and Johnson's earlier studies have not found the sex difference observed in those original studies (Moore & Johnson, 2008, 2011). For example, a study of slightly older infants using such stimuli and methods provided evidence of MR in both male and female 9-month-olds who had started to crawl (Schwarzer, Freitag, Buckel et al., 2013). Likewise, in a recent study of 4.5-month-olds using these same stimuli and methods, we found evidence of MR in both male and female infants who successfully habituated to our habituation stimulus (Slone et al., 2016).

In an effort to explain the sex difference sometimes observed in infants' performances in MR tasks, Quinn and Liben (2014) tested the possibility that a sensitivity to different angular rotations may contribute to the sex difference found in MR tasks. Specifically, they presented infants with familiarization and novel test rotations of their original stimulus at varying degrees of rotation. When compared to chance performance, both male and female infants discriminated between the familiar and novel rotations, suggesting that sensitivity to varying degrees of rotation probably does not contribute to the sex difference that has sometimes been observed in infant MR tasks. We are not aware of any other studies conducted to date that have been designed to determine what is responsible for the sex differences that have occasionally been seen in infant MR tasks.

Thus, it is not yet clear why some studies of MR in infants have found sex differences whereas others have not, but an increasing number of published studies indicate that a variety of methods and stimuli can produce sex differences, whereas other methods and stimuli can produce equivalent performances in male and female infants. Some studies in our laboratories have found sex differences (Moore & Johnson, 2008, 2011); others have not (Slone et al., 2016). Likewise, some studies of MR in infants tested in other researchers' laboratories have found sex differences (Lauer et al., 2015; Quinn & Liben, 2008, 2014); others have not (Frick & Möhring, 2013; Frick & Wang, 2014; Möhring & Frick, 2013; Schwarzer, Freitag, Buckel et al., 2013; Schwarzer, Freitag, & Schum, 2013). Although the studies conducted to date on MR in infants have not produced consistent results regarding the relations between participant sex and MR performance, this much is clear: the growing number of studies that have now been published on MR in infants confirm that many infants between 3 and 16 months of age are able to succeed in age-appropriate MR tasks.

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