The Official Journal of the International Society on Infant Studies
Infancy

Infancy, ***16***(4), 435–445, 2011

ISSN: 1525-0008 print / 1532-7078 online
DOI: 10.1111/j.1532-7078.2010.00058.x

WILEY-BLACKWELL

Mental Rotation of Dynamic, Three-Dimensional Stimuli by 3-Month-Old Infants

David S. Moore
Department of Psychology
Pitzer College and Claremont Graduate University

Scott P. Johnson
Department of Psychology
University of California

Mental rotation involves transforming a mental image of an object so as to accurately predict how the object would look if it were rotated in space. This study examined mental rotation in male and female 3-month-olds, using the stimuli and paradigm developed by Moore and Johnson (2008). Infants were habituated to a video of a three-dimensional object rotating back and forth through a 240° angle around the vertical axis. After habituation, infants were tested both with videos of the same object rotating through the previously unseen 120° angle, and with the mirror image of that display. Unlike females, who fixated the test displays for approximately equal durations, males spent significantly more time fixating the familiar object than the mirror-image object. Because familiarity preferences like this emerge when infants are relatively slow to process a habituation stimulus, the data support the interpretation that mental rotation of dynamic three-dimensional stimuli is relatively difficult—but possible—for 3-month-old males. Interpretation of the sex differences observed in 3- and 5-month-olds' performances is discussed.

Mental rotation refers to the process whereby a person can form a mental representation of an object and then modify that representation in a way that allows for the accurate prediction of how the object would appear if it

---

Correspondence should be sent to David S. Moore, Pitzer College, 1050 N. Mills Avenue, Claremont, CA 91711. E-mail: dmoore@pitzer.edu

were rotated in space. Mental rotation has been studied extensively since the 1970s (Shepard, 1978; Shepard & Metzler, 1971), both because it is of theoretical interest to cognitive scientists (Pylyshyn, 2002) and because it appears to be useful to individuals engaged in a wide variety of tasks, from recognizing individual letters of the alphabet (Rusiak, Lachmann, Jaskowski, & van Leeuwen, 2007; Rüsseler, Scholz, Jordan, & Quaiser-Pohl, 2005) to performing certain surgical (i.e., laparoscopic) procedures (Conrad et al., 2006).

Although hundreds of studies of mental rotation have now been published, research on the development of this ability has proceeded more slowly. In a comprehensive meta-analysis, Voyer, Voyer, and Bryden (1995) reported that only four out of 44 mental rotation studies conducted between 1947 and 1993 (i.e., 9%) had included participants younger than 10 years of age, and three of these studies were conducted between 1967 and 1971, before Shepard's classic work on mental rotation was published. In contrast, the past 12 years have seen the publication of an increasing number of studies of preschoolers in which tasks that requires some sort of mental rotation ability have been utilized; these studies have consistently reported evidence of mental rotation in at least some participants between 3 and 5 years of age (Estes, 1998; Frick & Newcombe, 2009; Levine, Huttenlocher, Taylor, & Langrock, 1999; Okamoto-Barth & Call, 2008).

In the mid-1990s, Rochat and Hespos (1996) and Hespos and Rochat (1997) reported that 4-month-old infants can form dynamic mental representations that allow them to track a two-dimensional (2D) object undergoing rotational motion in the frontal plane, an ability that can then be used to anticipate the object's ultimate orientation. These results were taken to constitute tentative evidence for rudimentary mental rotation in infants, but because the test displays used in these studies did not include a stimulus that was a mirror image of the familiarized 2D object, these studies are qualitatively different from the traditional mental rotation tasks presented to older children and adults.

The first reports of full-blown mental rotation in infancy did not appear until 2008. That year, two labs working independently reported converging data suggesting that at least in male infants, mental rotation ability begins to develop between 3.5 and 5 months of age (Moore & Johnson, 2008; Quinn & Liben, 2008). Quinn and Liben (2008) used static stimuli to test infants' abilities to mentally rotate a 2D stimulus in a 2D (frontal) plane, and Moore and Johnson (2008) used dynamic stimuli to test infants' abilities to mentally rotate a three-dimensional (3D) stimulus around a vertical axis, but both teams of researchers utilized test trials in which infants were required to discriminate between a familiarized object seen in a novel (rotated) position and a mirror image of that object. Both methods revealed a sex difference in behavior. Specifically, male infants in both studies preferred to fixate the mirror-image stimulus over the familiar stimulus, even though neither test stimulus had previously been seen; in contrast, female infants looked at the two test stimuli for approximately equal durations. The male infants' preferences were interpreted to mean that they recognized (and therefore were less interested in) the familiar object, even though it was now being seen in a novel position. Both teams of researchers argued that recognizing the rotated familiarization object required mental rotation.

To our knowledge, there has been only one other study of mental rotation in infancy. Schwarzer, Freitag, and Buckel (2010) examined the extent to which crawling experience influenced performance on a mental rotation task that utilized elements like those in Moore and Johnson's (2008) and Quinn and Liben's (2008) tasks. Specifically, Schwarzer et al. presented 9-month-olds with a series of static stimuli picturing images of 3D objects like those used by Moore and Johnson; as in Quinn and Liben's study, the infants saw these objects in discrete rotated positions across habituation trials. Like the other researchers, Schwarzer et al. reported a sex difference favoring males, however in this study, only male 9-month-olds who had begun to crawl provided evidence of mental rotation ability. In contrast, male infants who had not yet begun to crawl —and female infants regardless of whether or not they had begun to crawl—were equally likely to fixate a familiarized stimulus and its mirror image. Schwarzer et al. interpreted their noncrawling older boys' failure to provide evidence of mental rotation as reflecting the increased cognitive demands of their task over the tasks used by Quinn and Liben and by Moore and Johnson. The Schwarzer et al. task might have been more difficult for infants than the tasks used by these other researchers, because mental rotation of 3D objects appears to be more difficult than mental rotation of 2D objects (Linn & Petersen, 1985) and because dynamic rotating stimuli might facilitate mental rotation in a way that static images do not.

Quinn and Liben (2008) found evidence of mental rotation in 3.5-month-old male infants in a task utilizing static 2D images. The current study explores the possibility that mental rotation can be detected at this young age using the dynamic 3D stimuli developed by Moore and Johnson (2008). Based on the results of the latter study, we anticipated that if mental rotation can be detected in infants this young using Moore and Johnson's stimuli, it would be more likely to be observed in male, as opposed to female, 3-month-olds.

METHODS

Participants

The final sample consisted of 20 male and 20 female full-term 3-month-old infants (*M* age = 97.1 days, *SD* = 12.0). Six additional infants were observed but excluded from the analysis due to excessive fussiness.

Stimuli

Each stimulus (see Figure 1) was a video representation of a 3D object similar to the objects used by Shepard and Metzler (1971) in their mental rotation tasks; all stimuli used in this study were presented on a black background and were identical to those described in Moore and Johnson (2008). The object portrayed in one habituation and one test video will be referred to (arbitrarily) as the "L-object" and the object portrayed in the other two videos (one habituation and one test) will be referred to as the "R-object"; these two objects were mirror images of one another. Each habituation video was composed of 150 sequential perspective projections, and each of these projections represented the same object rotated an additional 1.6° around the vertical axis; when presented at 30 frames per second, this series of images appeared as an object rotating at 48° 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 videos of the L- and R-objects used for the test trials continued the rotation of the L- and R-objects,

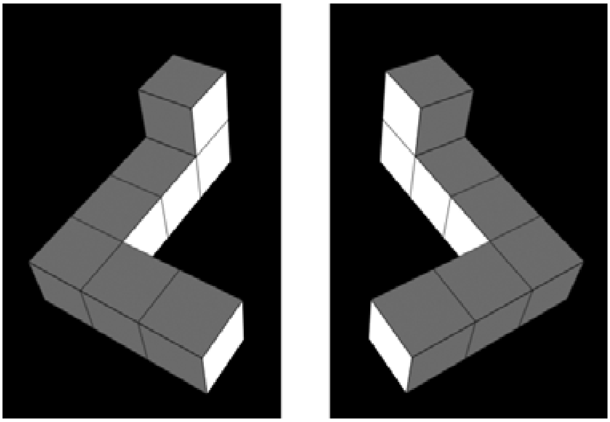

Figure 1 L- and R-habituation objects, pictured on the left and right, respectively.

respectively, through the previously unseen 120° of arc. Each of the 75 frames constituting a test video represented the habituation object rotating an additional 1.6° around the vertical axis. Thus, a habituation video and its corresponding test video together represented a complete 360° turn 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.

Apparatus and procedure

Infants were tested sitting on their parent's lap in a darkened room, 100 cm from a 53 cm monitor screen; parents kept their eyes closed throughout the procedure. A Macintosh G5 running Habit software (Cohen, Atkinson, & Chaput, 2002) presented stimuli on the monitor, timed trials, calculated the habituation criterion, and stored data. A trained observer, invisible to the infant and blind to the stimulus shown, viewed the infant via a closed-circuit camera and used the computer's keyboard to initiate trials and record the durations of the infants' fixations.

Each trial began when the observer pressed a key to indicate that an attention-getter stimulus, used prior to every trial, had drawn the infant's attention to the monitor. Each trial ended (i.e., the stimulus was terminated) either 2 sec after the observer released a key to indicate that the infant was no longer fixating the display, or after 60 sec (whichever came first). If the infant returned attention to the stimulus in the 2-sec interval, the trial continued.

Infants were randomly assigned to the L- or R-habituation group, meaning that in an initial series of identical habituation trials, they saw the habituation video portraying the L- or R-object, respectively; the use of these two groups effectively controlled for any spontaneous preferences infants might have had for the stimuli used in these studies. Each infant was deemed habituated when her average time fixating the habituation stimulus declined in a given four-trial block to 50% of her average time of fixation in the first four habituation trials. Therefore, each infant saw a minimum of five habituation trials. Once the infant was habituated (or after she had experienced 12 habituation trials, whichever came first), she saw a series of six test trials. Twenty randomly selected infants saw the L-test stimulus in the first test trial, and the other 20 infants saw the R-test stimulus in the first test trial. The stimulus presented in subsequent test trials was alternated thereafter.

RESULTS

The principal dependent measure in our experiment was looking time during test trials at familiar versus novel (mirror-image) versions of the habituation object, seen from a different perspective. Preliminary analyses examining the effects on looking times of order of test stimulus presentation and of habituation with the L- versus R-object revealed no reliable main effects or interactions that bore on the questions of interest; therefore data were collapsed across these variables for the following analyses.

A 2 (sex: male versus female) × 2 (test display: familiar versus novel) × 3 (test trial block: test trials 1 and 2 versus test trials 3 and 4 versus test trials 5 and 6) mixed analysis of variance yielded a reliable sex × display interaction, $F(1, 38) = 6.61$, $p = .014$, partial $\eta^2 = 0.15$. Simple effects tests revealed that male 3-month-olds looked longer at the familiar test object rotating through the novel angle than at the mirror-image test object, $F(1, 38) = 8.05$, $p = .007$, partial $\eta^2 = 0.28$ (see Figure 2); 65% of these infants preferred the familiar test stimulus (Wilcoxon $Z = 2.04$, $p < .05$; see Figure 3). In contrast, female 3-month-olds looked at the test stimuli about equally, $F(1, 38) = 0.64$, $p = .43$; 45% of these infants preferred the familiar test stimulus (Wilcoxon $Z = 0.48$, $p = .63$). Male and female infants' data did not differ in terms of accumulated habituation times, $t(38) = 0.68$, $p = .49$, or in number of trials to habituation, $t(38) = -1.45$, $p = .14$.

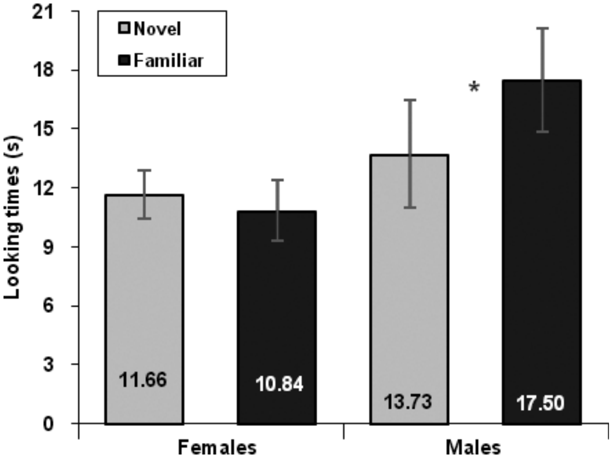

Figure 2 Three-month-olds' mean looking times at novel (gray bars) and familiar (black bars) test stimuli. Error bars indicate standard error of the mean, and an asterisk (*) indicates statistical significance, $p < .008$.

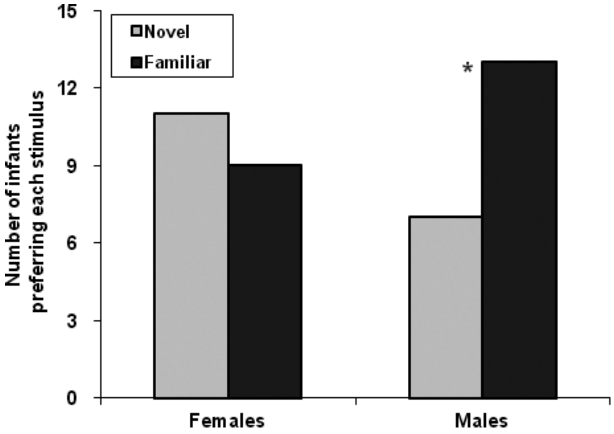

Figure 3 Number of 3-month-olds preferring the novel (gray bars) and familiar (black bars) test stimuli. Error bars indicate standard error of the mean, and an asterisk (*) indicates statistical significance, $p < .05$.

In summary, whereas female infants treated the test stimuli similarly, male infants spent less time in the test trials fixating the mirror-image object than the familiar object rotating through a novel angle.

DISCUSSION

Looking-time preferences for *novel* stimuli are usually observed when an infant is first habituated to a stimulus and then given an opportunity in test trials to look at both the familiar stimulus and a novel stimulus. Such results have traditionally been interpreted to mean that the infant recognizes the familiar stimulus and is no longer interested in looking at it because it is familiar (Fantz, 1964). Therefore, Moore and Johnson (2008) expected that if 5-month-old infants recognize a familiar object at test even as it is seen revolving through a novel angle, they should spend less time fixating that object, and should instead prefer to look at a mirror-image object. In fact, Moore and Johnson's 5-month-old male participants behaved like this, supporting the conclusion that these infants were able to recognize the familiar object from a new perspective because they were able to rotate at least one of their mental representations in order to compare it with the presented stimuli. In contrast, Moore and Johnson's 5-month-old female participants fixated the familiar and mirror-image objects for similar lengths of time.

Likewise, the 3-month-old female participants in the current study exhibited no preference for one test stimulus over the other, whereas the 3-month-old male participants did. However, unlike the 5-month-olds tested by Moore and Johnson (2008), the 3-month-old boys tested in the current study spent significantly more time, on average, looking at the *familiar* test stimulus. Because infants can fail to demonstrate discrimination for many reasons, we cannot be sure which of many possible interpretations of the female participants' behavior is correct, but because our male participants' preference for the familiar object over its mirror image was reliable, an explanation of their behavior must be sought.

Familiarity preferences are not extremely rare in studies of infant perception and cognition; they have been observed recently in several investigations, including (among others) studies on the detection of subtle relations in visual patterns (Fiser & Aslin, 2002), the learning of abstract rule-governed sequences (Johnson et al., 2009), and the segmentation of artificial speech from conflicting sources of information (Thiessen & Saffran, 2003). In an effort to explain such preferences, Hunter, Ames, and Koopman (1983) proposed a model designed to predict infants' looking times based on factors such as stimulus complexity, infant age, and familiarization time. According to their hypothesis, familiarity preferences following habituation will be more likely when infants have failed to complete their processing of a stimulus despite having reached a criterion for habituation (Hunter & Ames, 1988). In such cases, infants are thought to remain attentive to a previously seen display because they are trying to obtain additional information from a stimulus that was still being processed when the habituation trials ended. Likewise, fixation duration has been linked to speed of processing; long looking times are thought to reflect the need for extended exposure to attend to, encode, and retain stimulus properties (Colombo, 1995; Roder, Bushnell, & Sasseville, 2000). If either or both of these accounts are correct then familiarity preferences should be unsurprising in cases where familiarization times are relatively short, where the stimuli to be processed are relatively complex, or when the infants being tested are relatively young (because younger infants can, in general, be expected to process information more slowly than older infants). For these reasons, posthabituation familiarity preferences have been interpreted as reflecting a cognitive or perceptual operation that is especially complex for the infant engaged in it.

Because the male infants in this study exhibited a reliable preference for the familiar stimulus in spite of the fact that the test stimuli were *identical* except for their L- or R-identities, their looking times were functions of those identities. Furthermore, because they preferred to look during the test trials at the objects to which they had been habituated, the unequal looking times we observed in the test trials reflect the infants' detection of a relationship between the habituation stimuli and the test stimuli, even though both of the test stimuli presented never-before-seen perspectives of the test objects. Consequently, a parsimonious interpretation of our results is that during the test trials, the 3-month-old males in this study, like the 5-month-old males in Moore and Johnson (2008), rotated either a mental representation of the habituation object (allowing comparison to the visible test stimulus) or a mental rotation of the visible test stimulus (allowing comparison to a mental representation of the habituation object). It is also possible that their performance reflected rotation of mental representations of both the habituation and the test objects.

Thus, mental rotation of a 3D object seen rotating around a vertical axis appears to be possible for 3-month-old males, but because these infants exhibited a familiarity preference whereas 5-month-olds responded to these same stimuli with a novelty preference, the Hunter et al. (1983) and Colombo (1995) models suggest that the task is more difficult for 3-month-old than for 5-month-old males. In addition, because the current finding of a familiarity preference contrasts with Quinn and Liben's (2008) finding of a novelty preference, we can hypothesize that for infants between 3 and 3.5 months of age, mental rotation of dynamic 3D stimuli is more difficult than mental rotation of static 2D stimuli. Therefore, stimulus complexity may play an important role in the development of mental rotation ability, just as age does. We are currently developing stimuli that will allow us to test this hypothesis in future studies.

Another issue raised by this interpretation is the possibility that the behavior we have observed in female infants cannot be taken as evidence that they do not engage in mental rotation. The absence of significant effects in both 3- and 5-month-old female populations could be a reflection of novelty preferences being displayed by some of these infants and familiarity preferences being displayed by others, the net effect being no detectable preferences at all on average. In such a case, both groups of infants might be capable of mental rotation, but the difference between them—a difference related to how challenging each subpopulation finds the task—would have the effect of producing insignificant results overall. The bimodality that might be expected in such situations has not characterized the data sets we have collected so far, but given the variability typical of infants' looking times, this finding alone cannot rule out this alternative hypothesis. Another way to evaluate the hypothesis would be with an independent method—for example, eye tracking—that allows for the identification of infants who are likely to exhibit familiarity versus novelty preferences in this task. We are continuing to actively investigate this hypothesis in our labs.

ACKNOWLEDGMENTS

Supported by Pitzer College's R&A Committee (D.S.M.) and N.I.H. grants R01-HD40432 and R01-HD48733 (S.P.J.). We thank our participants, and Dona Bailey, Robert Ditto, and Dawn Moore for invaluable help with this work.

REFERENCES

Cohen, L. B., Atkinson, D. J., & Chaput, H. H. (2002). Habit 2002: A new program for obtaining and organizing data in infant perception and cognition studies (version 1.0) [Computer Software]. Austin, TX: The University of Texas.

Colombo, J. (1995). On the neural mechanisms underlying developmental and individual differences in visual fixation in infancy: Two hypotheses. *Developmental Review*, *15*, 97–135.

Conrad, J., Shah, A. H., Divino, C. M., Schluender, S., Gurland, B., Shlasko, E., & Szold, A. (2006). The role of mental rotation and memory scanning on the performance of laparoscopic skills: A study on the effect of camera rotational angle. *Surgical Endoscopy and Other Interventional Techniques*, *20*, 504–510.

Estes, D. (1998). Young children's awareness of their mental activity: The case of mental rotation. *Child Development*, *69*, 1345–1360.

Fantz, R. L. (1964). Visual experience in infants: Decreased attention to familiar patterns relative to novel ones. *Science*, *146*, 668–670.

Fiser, J., & Aslin, R. N. (2002). Statistical learning of new visual feature combinations by infants. *Proceedings of the National Academy of Sciences (USA)*, *99*, 15822–15826.

Frick, A., & Newcombe, N. S. (2009, October). *Measuring mental rotation in 4-year-olds using a nonverbal touch screen paradigm*. Poster presented at the VI biennial meeting of the Cognitive Development Society, San Antonio, TX.

Hespos, S. J., & Rochat, P. (1997). Dynamic mental representation in infancy. *Cognition*, *64*, 153–188.

Hunter, M. A., & Ames, E. W. (1988). A multifactor model of infant preferences for novel and familiar stimuli. In L. P. Lipsitt (Ed.), *Advances in child development and behavior* (pp. 69–95). New York: Academic Press.

Hunter, M. A., Ames, E. W., & Koopman, R. (1983). Effects of stimulus complexity and familiarization time on infant preferences for novel and familiar stimuli. *Developmental Psychology*, *19*, 338–352.

Johnson, S. P., Fernandes, K. J., Frank, M. C., Kirkham, N. Z., Marcus, G. F., Rabagliati, H., & Slemmer, J. A. (2009). Abstract rule learning for visual sequences in 8- and 11-month-olds. *Infancy*, *14*, 2–18.

Levine, S. C., Huttenlocher, J., Taylor, A., & Langrock, A. (1999). Early sex differences in spatial skill. *Developmental Psychology*, *35*, 940–949.

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development*, *56*, 1479–1498.

Moore, D. S., & Johnson, S. P. (2008). Mental rotation in human infants: A sex difference. *Psychological Science*, *19*, 1063–1066.

Okamoto-Barth, S., & Call, J. (2008). Tracking and inferring spatial rotation by children and great apes. *Developmental Psychology*, *44*, 1396–1408.

Pylyshyn, Z. W. (2002). Mental imagery: In search of a theory. *Behavioral and Brain Sciences*, *25*, 157–182.

Quinn, P. C., & Liben, L. S. (2008). A sex difference in mental rotation in young infants. *Psychological Science*, *19*, 1067–1070.

Rochat, P., & Hespos, S. J. (1996). Tracking and anticipation of invisible spatial transformations by 4- to 8-month-old infants. *Cognitive Development*, *11*, 3–17.

Roder, B. J., Bushnell, E. W., & Sasseville, A. M. (2000). Infants' preferences for familiarity and novelty during the course of visual processing. *Infancy*, *1*, 491–507.

Rusiak, P., Lachmann, T., Jaskowski, P., & van Leeuwen, C. (2007). Mental rotation of letters and shapes in developmental dyslexia. *Perception*, *36*, 617–631.

Rüsseler, J., Scholz, J., Jordan, K., & Quaiser-Pohl, C. (2005). Mental rotation of letters, pictures, and three-dimensional objects in German dyslexic children. *Child Neuropsychology*, *11*, 497–512.

Schwarzer, G., Freitag, C., & Buckel, R. (2010, March). *Mental rotation in 9-month-old infants: The role of gender and self-induced locomotion*. Poster presented at the XVIIth biennial International Conference on Infant Studies, Baltimore, MD.

Shepard, R. N. (1978). The mental image. *American Psychologist*, *33*, 125–137.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, *171*, 701–703.

Thiessen, E. D., & Saffran, J. R. (2003). When cues collide: Use of stress and statistical cues to word boundaries by 7- to 9-month-old infants. *Developmental Psychology*, *39*, 706–716.

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, *117*, 250–270.