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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
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Abstract

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Studies have shown consistent sex differences in mental rotation ability, in which males have an advantage as early as infancy. Males and females also differ in their preferenes for certain objects. Research has attributed the sex differences in mental rotation and object preferences to biological features (e.g., testosterone) and environmental influences (e.g., socialization, parental reinforcement), and has even suggested a bidirectional influence. The current study used a novel mental rotation task and a preferential looking paradigm to explore individual differences in mental rotation and object preference in 6- to 14-month-old infants to investigate the relation between the two cognitive features early in life. Our results showed that males and females did not differ in their mental rotation performance. Across genders, infants visually preferred a doll (i.e., animate) to a truck (i.e., inanimate). The relation between mental rotation and preference for the truck varied by gender. Whereas visual preference for a truck was associated with mental rotation ability in boys (not accounted for by age), there was no such relation in girls. Possible explanations for this difference are discussed.

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Understanding Early Sex Differences in Mental Rotation

A type of spatial skill, mental rotation has generated a multitude of investigations in the field of cognition. Mental rotation refers to "the ability to rotate quickly and accurately two- or three-dimensional figures, in imagination" (Linn & Petersen, 1985, as cited in Voyer, Voyer, & Bryden, 1995, p. 250) and consistently shows the largest difference between males and females among various visuospatial tasks (Voyer et al., 1995), a finding that seems particularly relevant in a society where males tend to occupy more spatially-relevant domains, like science and engineering (Halpern et al., 2007). Object preference, another arena that highlights sex differences, has shown biological (Connellan, Baron-Cohen, Wheelwright, Batki, & Ahluwalia, 2000; Hassett, Siebert, & Wallen, 2008) as well as social roots (Liben & Bigler, 2002; Martin & Halverson, 1981; Miller, Trautner, & Ruble, 2006)

More generally, engagement in certain activities (e.g., block-building) has been related to spatial abilities (Baenninger & Newcombe, 1989; Tracy, 1987). The current study aims to merge the two realms of mental rotation and object preference to help shed insight on the developmental origins and mechanisms underlying sex differences in mental rotation. Our examination may elucidate how certain factors interact to produce differentiating outcomes between men and women on tests of mental rotation.

An extensive literature explores sex differences in various tasks of spatial perception and reasoning. Of these, mental rotation shows the largest disparity, with a male advantage in terms of speed and accuracy (for review, see Voyer et al., 1995). Such advantage strengthens with age in relation to females (Voyer et al., 1995). Shepard and Metzler's (1971) seminal study on mental rotation involved asking participants to compare two 2-dimensional drawings of 3-dimensional block structures and decide whether one drawing was a rotation of the other, or its mirror image. While research shows that the sex difference in several visuospatial tasks has decreased over historical time, Voyer et al. (1995) found the reverse trend for mental rotation. With respect to mental rotation, the disparity between the sexes has increased over the years. Social change has actually increased sex differences on tests of mental rotation, which is consistent with the possibility of a strong biological influence. Environmental factors, such as experience with spatially relevant activities (e.g., videogames) must also be considered as contributions to the recently increased sex difference (Richardson, Powers, & Bousquet, 2011).

Theory suggests that playing with certain toys (e.g. blocks), with which boys have more experience than girls, provides practice with mental manipulations and transformations of two- and three-dimension figures. Such practice may contribute to the male advantage in spatial abilities (Tracy, 1987). Consistent with this theory, which emphasizes the importance of environmental factors, male advantage varies across children from different groups of socioeconomic status (SES) (Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005). Although 2nd and 3rd grade boys from middle and high-SES backgrounds outperformed their female peers on two spatial tasks, one of which involved mental rotation, there was no sex difference in the low-SES group (Levine et al., 2005). Levine and colleagues (2005) suggest the male advantage may disappear in the low-SES group because of boys' limited availability of certain games and toys that promote spatial skills, which are usually expensive (e.g., Legos and videogames). Additionally, ability to explore the environment has been related to gender differences in spatial skills, an activity in which boys partake more than girls (e.g., Entwisle, Alexander, & Olson, 1994, as cited in Levine et al., 2005). Parents in low-SES neighborhoods perceive local danger and are less permissive in allowing exploratory behavior than their higher-SES counterparts (e.g., O'Neil, Park, & McDowell, 2001, as cited in Levine et al., 2005), which may hinder necessary experiences to foster the male advantage. Thus, environmental factors are essential to supporting the advantage of spatial skills, at least in males. Since spatial skills are not rigid from birth, but are instead flexible, understanding the nature and development of sex differences may serve to ameliorate gender issues surrounding underrepresentation of women in career fields like science and engineering.

Visuospatial abilities in particular are associated with occupations such as physics, engineering, and chemistry (Smith, 1964; Snow & Yalow, 1982; Sorby, & Baartmans, 2000, as cited in Halpern et al., 2007). The National Science Board (2003) announced a shortage in jobs that require high-level math thinking and science skills (Halpern et al., 2007). National Science Foundation data show that "Women made up almost one-fourth (24 percent) of the [science and engineering] workforce but close to one-half (46 percent) of the U.S. workforce, in 1999" (Halpern et al., 2007). Additionally, if women perform significantly worse on visuospatial tasks such as mental rotation, it could be disadvantageous for many reasons, including limitations in both employment options and important skills for functioning in increasingly technological environments. One such career limitation is that women obtain doctorates in natural sciences and engineering at lesser proportions than men, but the difference is eliminated when mathematical ability is accounted for (Baker, 1998, as cited in Halpern et al., 2007). There may be connections between math and visuospatial abilities. Enhancing females' skills in science and math could refuel the workforce with needed females who are advanced mathematicians and scientists. Understanding when and how mental rotation emerges is thus a worthwhile investigation, not only because it shows the largest sex difference of any visuospatial ability, but also because the sex difference on the Mathematics portion of the SAT (SAT-M) disappeared when questions of mental rotation were statistically removed (Caseu, Nuttall, Pezaris, & Benbow, 1995, as cited in Halpern et al., 2007).

Recent research suggests that the male advantage in mental rotation may emerge as early as infancy (Quinn & Liben, 2008; Moore & Johnson, 2008; Moore & Johnson, 2010). Quinn and Liben conducted a study in which 3- to 4-month-old infants were familiarized to a 2-dimensional image of the number one ("1") in seven 15-s trials. The image appeared in seven different 45-degree rotations between 0 and 360 degrees that were presented randomly (see Figure 1). Two identical copies of each stimulus were presented in each trial. In two 10-s test trials, infants were presented with two images of the number one: not previously seen during familiarization and its mirror image. Boys had a novelty preference for the mirror image, whereas girls showed no preference, dividing visual attention equally between the two images. It has been suggested that the male preference for the mirror image is due to more advanced mental rotation abilities because males recognize the mirror image as an anomaly in the rotation sequence.

In another study, Moore and Johnson (2008) tested 5-month-old infants using a habituation/dishabituation paradigm. In the habituation phase, infants were presented with a 3-dimensional object that rotated around a vertical axis (in depth), through a 240-degree arc. In the test phase, the habituation object and its mirror image revolved through a novel 120-arc that started at the end point of the habituation video, thus completing a 360-degree rotation. During these trials, boys spent more time looking at the mirror image. Girls showed no preference, spending an equal amount of time looking at both the habituation object and its mirror image. Because boys discriminated the two, and girls did not, it suggested that boys were better at mental rotation. This study suggests that pre-verbal male and female infants differ in their mental rotation ability. However, because looking times during test were not compared to looking times at the end of habituation, it is unclear whether or not girls dishabituated to both types of test trials, which would suggest that they may have been more sensitive to the differences in arc between habituation and test. Girls may have dishabituated to both types of test trials, although it is unclear since we do not know how their looking times during test trials compare to those during habituation.

More recently, Moore and Johnson (2010) used the same stimuli and paradigm to study mental rotation in 3-month-olds. As in the previous study, they found that boys discriminated between the habituation object and its mirror image. However, unlike the previous study, males spent more time fixating the familiar object than its mirror image. Similar to the last study, females spent about equal time looking at both objects. To account for greater looking to familiar test trials instead of novel test trials, the authors suggested that boys may have not habituated to the familiar stimulus during habituation. The stimulus was still considered novel during test trials, hence their familiarity preference. According to Hunter and Ames (as cited in Moore & Johnson, 2010), infants are more likely to prefer a familiar stimulus after habituation when they have not finished processing a stimulus. Younger infants process information more slowly than older ones, so post-habituation familiarity preference may indicate cognitive difficulty for the participant.

Object Preferences

Males and females have also been shown to differ in the types of objects they prefer, and, as I argued above, the sex difference is not likely due to socialization alone but may also be due to biology. Socialization sustains sex differences that may lead boys and girls to prefer different objects and toys. Research supports parents' and other adults' "modeling and reinforcement of gender-typical toy play" in experimental (Pasterski et al., 2005, as cited in Alexander, Wilcox, &

Woods, 2009, p. 427-428) and naturalistic settings (e.g., Fagot, 1978, as cited in Alexander et al., 2009). Parents reinforce gender-typical play through explicit praise or punish it using overt criticism. More implicitly, they may even partake in play with the child or retreat from the child (Pasterski et al., 2005, as cited in Alexander et al. 2009). In a study conducted by Alexander and colleagues (2009), 3- to 8-month-old boys showed no visual preference for a pink doll or a blue truck when presented with both, whereas girls fixated more on the doll than the toy truck. When comparing looking times to the truck alone, boys showed a significantly greater number of visual fixations on this object than the girls. With respect to the doll, girls showed a greater number of visual fixations, but the effect was not significant. One explanation for this finding is that parents provide their children with gender-typical toys as early as infancy. Consequently, affinity for an object may be *experience-dependent*, since toys acquire qualities that evoke positive emotion through familiarity and associations with caregivers (Pomerleau, Bolduc, Malcuit, & Cossette, 1990, as cited in Alexander et al., 2009). Greater visual fixation could indicate familiarity or actual preference independent of familiarity. However, visual fixations are difficult to interpret because preferential looking paradigms are ambiguous with respect to what greater looking times (greater attention) to a particular image means.

Yet the gender difference in object preference may exist even without socialization, since biological influences also have an impact. Studies conducted on human newborns and rhesus monkeys demonstrate the potency of biological preference, since the effects of socialization are minimal, and, in the case of monkeys, non-existent. Connellan and colleagues (2000), for example, found that female neonates exhibited a preference for a woman's face, (i.e., social objects), whereas male neonates looked longer at a mobile, which, according to the authors, is a "physical-mechanical object" (p. 113). Toy preferences in rhesus monkeys parallel those of human children in that male monkeys preferred wheeled toys (i.e., mechanical object), whereas females showed variability, with a moderate preference for female-typical toys (Hassett et al., 2008). Even without societal influence, these populations still demonstrate an inclination for gender-typical objects. Hassett et al. (2008) suggested that toy preferences could result from a proclivity for certain activities, like active manipulation or cradling, which can be adequately performed based on certain toy features. It has been suggested that different prenatal hormone exposure in males and females may influence such activity bias (Cohen-Bendahan, van de Beek, & Berenbaum, 2005; Pasterski et al., 2005; Alexander, 2006).

Potential Biological Influences

Since socialization alone does not appear to account for the sex difference in toy preferences and may instead be attributed to biological forces, as shown in the studies with human newborns and rhesus monkeys, one should explore how mental rotation may also be influenced by biology. Studies have shown biological support for a male advantage in mental rotation performance (Bull & Benson, 2006). Digit ratio is a proxy for prenatal androgen exposure, and higher testosterone levels produce a lower digit ratio (Lutchmaya et al., 2004; Manning, 2002; Manning et al., 1998, as cited in Bull & Benson, 2006). The right hand's digit ratio has been found to be more dimorphic than the left in humans (Manning, 2002; Manning et al., 1998; McFadden & Schubel, 2002; Williams et al., 2000, as cited in Bull & Benson, 2006). Many studies have shown that lower digit ratios of the right hand predict better performance on various types of spatial tasks (e.g., mental rotation) as well as mathematical tasks (Castho et al., 2003b; Fink et al., in press; Kempel et al., 2005; Luxen & Buunk, 2005; Manning & Taylor, 2001; McFadden & Schubel, 2003, as cited in Bull & Benson, 2006), although others have not shown a significant association between digit ratio and mental rotation or have found an inverse relation (Austin et al., 2002; Coolican and Peters, 2003; Pulin et al., 2004; Putz et al., 2004; Van Anders and Hampson, 2005, as cited in Bull & Benson, 2006). Differences among the studies in allowing use of various strategies (e.g., verbal vs. spatial) may explain the inconsistent findings (Bull & Benson, 2006).

An example of biological impact on spatial skills, independent of sex, is that young girls with congenital adrenal hyperplasia (CAH), a condition that causes above-average levels of androgens during prenatal and early postnatal development, play more with male-typical toys and prefer male playmates compared to their unaffected female counterparts. Male-typical activity extends into adulthood (Cohen-Bendahan et al., 2005). Studies suggest that females with CAH perform similarly to males on test of spatial skill tests. Environmental influences, such as engagement in certain activities, may mediate the relation between androgens and spatial ability.

One study conducted by Grimshaw, Sitarenios, and Finegan (1995) found a positive association between rate of mental rotation and prenatal testosterone levels in 7-year-old girls. In the mental rotation task, two (black-and-white) pictures of bears were presented simultaneously on a computer screen. The figures had the same arm raised for half the trials and different arms raised for the other half. By using one of two buttons, children reported whether the arms raised were the same or different. The bear on the left side of the screen was positioned upright, while the bear on the right side of the screen was situated upright or rotated clockwise (30, 60, 90, 120, 150, or 180 degrees) along the picture plane. Among those who showed evidence of mental rotation, as indicated by a strong relationship between response time and orientation of the stimuli (i.e., degree of rotation between the two stimuli), females responded more quickly than males, but approximately the same as males in terms of accuracy.

In another study, 18- to 22-year-old women and men who visually preferred male-typical toys (e.g., ball) compared to female-typical toys (e.g., doll) had significantly better targeting ability and smaller digit ratios (Alexander, 2006). The author concluded that high levels of prenatal androgens sustain preferences for male-typical objects and gender-typical characteristics vary according to visual preference for gender-linked toys. Taken together, these studies suggest an important influence of biology on mental rotation ability.

Current Study

Given that sex differences in mental rotation performance have been documented throughout development, from infancy to adulthood, and its position as the most diversifying skill between men and women among all visuospatial skills, the current study was designed to investigate individual differences early in development. We seek to uncover factors associated with its emergence using a novel mental rotation task. We also include a preferential looking paradigm consisting of gender-stereotyped objects to better understand the nature and potential mechanisms underlying early sex differences in mental rotation ability. Together, these measures allow us to test two main predictions. Is there an association between mental rotation performance and object preference in infancy? If so, is the same association seen for boys and girls? As found by Alexander and colleagues (2009), one prediction is that greater preference for inanimate objects will be positively correlated with spatial abilities for both males and females. Furthermore, a classic study conducted by Baenninger & Newcombe (1989) found a connection between engagement in certain activities and spatial ability in males and females.

To evaluate mental rotation ability in the present study, we designed a visual detection paradigm. Looking times of infants served as the dependent measure. The method is adapted from a paradigm originally crafted by Ross-Sheehy, Oakes, and Luck (2003) to measure infants' visual short-term memory through color change detection and later used by Libertus and Brannon (2010) to test infants' sensitivity to differences in numerosity. Libertus and Brannon presented infants with two streams of rapidly changing images on peripheral monitors. One of the streams did not change in numerosity and the other stream alternated between two different numerosities**.** On average, infants looked longer at the numerically-changing stream compared to the numerically-constant stream, suggesting that they discriminated between the two numbers and preferred the stream with greater variation. Infants looked longer at the changing stream compared to the constant stream because the novel numerosity violated their expectation of a homogeneous pattern of number. Infants similarly looked longer at the changing stream than the constant stream when the number of squares was within their short-term memory capacity (Ross-Sheehy et al., 2003). In order to determine whether or not infants looked longer at the changing numerosity stream than the constant stream because of short-term memory capacity or quantitative capacities, Libertus and Brannon compared performance in the numerical and color change detection task. A positive correlation between performances on both tasks would suggest they were measuring short-term memory capacity; however, the numerical and color change detection task scores were not associated, so quantitative capacities were likely responsible for performance on the numerical change detection task. The study found that numerical discrimination at 6 months of age predicted numerical discrimination abilities but not visual short-term memory at 9 months.

In the current study, we adapted the change detection paradigm to test infants' ability to engage in mental rotation. Infants were shown two streams of rapidly changing images. One stream contained images that changed in degree of rotation (clockwise and counterclockwise directions), but remained constant in its orientation around the picture plane (i.e. "non-changing" image stream). The other stream contained images that changed identical degrees of rotation but flipped (i.e., mirror reversal) across the picture plane (i.e., changing image stream). It was hypothesized that if infants could discriminate between the stream whose every third image flips (changes) within the picture plane and the stream whose images do not flip (non-changing), they would look longer at the changing stream than the non-changing stream. A visual preference for the changing stream would suggest mental rotation ability, since the changing stream violates the expectation that the image will rotate along the picture plane. While we predicted that infants would look longer at the changing stream, as young 3- to 4-month-old and 5-month-old male infants fixated more on a novel stimulus than a familiar one (Quinn & Liben, 2008; Moore & Johnson, 2008), it is possible that they could instead look longer at the non-changing stream, as 3-month-old male infants have also fixated more on a familiar stimulus than a novel one (Moore & Johnson, 2010). Alternatively, infants may show no preference, as female infants have shown no visual preference for a novel or familiar stimulus (Quinn & Liben, 2008; Moore & Johnson, 2008; Moore & Johnson, 2010).

Immediately following the mental rotation task, infants participated in a preferential looking task in which a blue truck teetered slightly in a fixed position on one side of the screen and a pink doll teetered slightly in a fixed position on the other side. The blue truck and pink doll parallel the stimuli used by Alexander and colleagues (2009). Alexander's (2006) findings support our prediction that preferences for inanimate objects would positively correlate with spatial abilities, in this case, mental rotation. In other words, infants who looked longer at the truck than the doll would also look longer at the changing image stream than the non-changing image stream, and thus those who preferred inanimate objects were better at mental rotation than those who preferred animate ones.

Method

Participants

The final sample consisted of 37 infants, including 12 females (*M* = 10.01 months, range = 6.33 m to 13.77 m) and 25 males (*M* = 10.66 months, range = 6.57 m to 13.67). Parents provided written informed consent for their infants. They were compensated for parking costs, given a certificate signifying their infant's participation, and received a t-shirt for their infant. All procedures were approved by the Institutional Review Board at Emory University.

Design

Infants were presented with two image streams simultaneously on one frontal screen. The two image streams were dynamic, presenting static images repeatedly (see Figure 2). One image stream was presented on the far left and the other on the far right. One image stream contained a two-dimensional figure within the picture plane (non-changing image stream). The other image stream was identical except that on every 3rd presentation it was flipped (i.e., appeared as mirror reversal). A two-dimensional figure, which resembled a Tetris piece, was used, since Quinn and Liben (2008) showed infants could mentally rotate such figures.

Following the mental rotation task, infants were presented with an object preference task. In this task, infants saw an image of a doll on one side of the screen and a toy truck on the other. Both objects teetered slightly back and forth.

Stimuli

The 2-dimensional stimulus was a red Tetris-like figure (19.44 cm^2) that likened a flattened side of a 3-dimensional Shepard-Metzler object used in Moore and Johnson's mental rotation task (Moore & Johnson, 2008). On each trial, the stimulus was presented repeatedly – each time for 500 ms, which an interstimulus interval (ISI) of 300 ms (blank screen). The images (approximately 47 cm apart) for both streams were identical, except that every third image in the changing-image stream flipped, appearing as a mirror reversal (see Figure 2). Each one of the four trials included orientations of the two-dimensional figure at 14-degree rotations, presented in a random order, within a range of 180 degrees of rotation: 0-180, 90-270, 180-360, and 270-90 degrees, respectively. The range was limited to increase the likelihood that infants could do the task. In the second condition, the trials were presented in reverse order. An image never repeated an orientation across the four trials. The pink doll and blue truck had the same dimensions of 13.5 cm in length and 10.5 cm in width and were spaced about 34 cm apart.

Apparatus and Procedure

Infants sat in a high chair or on their parent's lap in a darkened room, about 80 cm away from the center of an 83-inch (diagonal) screen. Parents were instructed to keep their eyes closed throughout the procedure so their infant would not get distracted or obtain their parent's visual cues. The experimenter shook a rattle on- and off-screen on both the left and right sides of the screen where the stimuli would be presented to allow for calibration and ensure integrity of the coding of looking times, which was done from video recordings. A Macintosh iMac desktop running Habit software (Cohen, Atkinson, & Chaput, 2002) presented stimuli, timed trials, and stored data. Before each trial, infants were presented with an auditory and visually-stimulating attention-getter on the center of the screen to draw infants' attention to the screen. The experimenter manually started each trial when the infant looked at the attention-getter, initiating each trial by pressing a key.

Each of the four mental rotation task trials lasted approximately 1 minute. The two trials in the object preference task lasted 30 seconds each. The side (left or right) of the changing image stream and truck switched between trials for each infant, and the order was counterbalanced across infants. For example, on the first trial of each task, half the infants (within sex) were presented with the changing image stream and truck; the other half of infants saw the reverse.

Participants' looking behavior was digitally recorded for later manual coding. A reliable coder recorded infants' looking behavior to the screen from videotape records. A second observer coded 24 participants. Coders were blind to the sides of the presentation of the stimuli in both the mental rotation task and the object preference task. Reliability between the two observers was high (r = 0.99).

Results

We analyzed the proportion of time each infant spent looking at the changing and non-changing image streams in the mental rotation task as well as the time spent looking to doll and truck in the preferential looking task. We then computed a proportion of looking time for each infant. Analyzing the proportion of total looking time eliminated individual differences in overall time spent looking at both image streams. Because the side (left or right) of the changing image stream and truck alternated across trials, infants may have had difficulty in adjusting to the side alternation and thus continued looking at one side of the screen, expecting to see the stimulus that was positioned on that side in the previous trial. Therefore, even though subsequent trials showed effects in the same direction as the first trials of each task, data from only the first trial of each task were used in analyses because they were the least affected by carryover.

We compared performance between boys and girls on the mental rotation task, using a between-subjects 2 X 2 ANOVA between two variables: type of image stream (changing or non-changing) and sex. There were no effects or interactions between the variables (p = n.s.). Using another 2 X 2 ANOVA between two variables, type of object (doll or truck) and sex, we found no overall sex difference on the object preference task (p = n.s.). To analyze performance on the first trial of the mental rotation task in males and females, a paired-samples t-test was conducted to compare the proportion of looking time to the changing image stream and non-changing image stream. Males showed no significant difference in their proportion of looking time to the changing image stream (M=49.77%, SD=.187) and non-changing image stream (M=50.23%, SD=.187); $t(25)=-.063$, $p = .95$. Females also showed no significant difference in their proportion of looking time to the changing image stream (M=49.57%, SD=.193) and non-changing image stream (M=50.43%, SD=.193); $t(13)=-.083$, $p = .935$ (see Figure 3). An examination of Figure 3 reveals that while the means suggest there are no significant differences in looking times to the changing and non-changing image streams, especially boys appeared to fall into two groups: some infants who looked longer to the changing image stream and some who looked longer to the non-changing image stream, as opposed to most infants not discriminating between the two. Using Pearson's correlation coefficient, further analyses computed on age exposed no relationship between age and the proportion of time spent looking at the changing image stream in boys ($r = .003$, $p = .987$) or girls ($r = -.111$, $p = .707$).

The first trial of the object preference task replicated previous findings (Alexander, 2006) in girls, who preferred the doll (M=67%, SD=.11) to the truck (M=33%, SD=.17); $t(11)=5.421$, $p = .000$, but not quite in boys, who also preferred the doll (M=60%, SD=.17) to the truck (M=40%, SD=.17); $t(24)=3.052$, $p = .005$, (see Figure 4). However, a greater proportion of males than females preferred the truck to the doll (males: 7 of 25; females: 1 of 12). Additional analyses conducted on age revealed a positive correlation with looking time to the truck for males that was marginally significant ($r = .36$, $p = .077$). In contrast, correlation analyses revealed no significant association between age and looking to the truck for girls ($r = -.373$, $p =$

.232). Both boys and girls preferred the doll to the truck, although a greater percentage of boys than girls preferred the truck. Looking to the truck was positively associated with age in boys, but age did not relate to looking to the truck or doll in girls.

Pearson's correlation coefficient was computed to test the predicted association between visual preference for an inanimate object (i.e., truck) and mental rotation ability. Analyses revealed that the proportion of time males spent looking at the changing image stream was positively correlated with the proportion of time they spent fixating the truck ($r = .538$, $p = .006$; see Figure 5), suggesting that mental rotation ability may impact object preference, or vice versa. There may also be a third variable (e.g., testosterone) that influences mental rotation and object preference in the same direction (see Discussion). In contrast, females showed no significant association between proportion of time spent fixating the changing image stream and proportion of time spent fixating the truck ($r = .012$, $p = .970$; see Figure 6), suggesting that mental rotation ability and object preference may not be influence one another or be affected in the same direction by some third variable.

Above we showed that age was positively correlated with proportion of looking time to the truck. Given the positive correlation between the proportion of time spent looking at the truck and the proportion of time spent looking at the changing image stream, we conducted additional analyses to examine the extent to which age might account for this association. Partial correlation analyses, controlling for age, suggested that the positive correlation between looking to the changing image stream and looking to the truck was not accounted for by age ($r_p = .562$, $p = .004$).

To summarize, there was no overall difference between boys and girls on the mental rotation task or the object preference task. While males and females did not prefer one image stream to the other, they both showed a preference during the preferential looking task. Even though a greater percentage of males than females preferred the truck, they both preferred the doll to the truck. Male preference for the truck was positively correlated with age, whereas females showed no such relationship for the truck or doll. Male preference for the truck was also positively associated with changing image stream preference. Alternatively, females showed no association in looking behavior between the mental rotation task and the preferential looking task. When male age was controlled, the association between toy truck preference and changing image stream preference still existed. In other words, age did not account for the relationship between toy preference and changing image stream preference in males.

Discussion

The motivation of the present study was to understand early sex differences in mental rotation ability, using a novel mental rotation task that assessed individual differences in object preference. Understanding when and how males and females differ in their mental rotation ability and desire for certain objects may be beneficial to discovering ways to intervene on females' behalf in order to advance their spatial skills in relation to males. Doing so may afford them a better opportunity to enter male-dominated fields like science and engineering, which involve the use of spatial skills. Because numerous studies have related differences in object preferences between boys and girls to their differences in spatial skills, attributing these disparities to biological and environmental factors that work both independently and interactively, the present study examined pre-verbal infants, who have been less influenced by socialization than most other cohorts. Limiting the effect of socialization may shed light on the factors that lead males and females to behave differently from one another on assessments of this specific spatial ability and penchant for certain toys.

The results from this study suggest that there were some similarities between 6- to 14-month-old boys and girls, such as performance on the mental rotation task and object preference, as well as differences. Boys showed an association between mental rotation and object preference, but girls did not. There was no sex difference in mental rotation ability, since males and females both showed no preference for the changing-image stream or non-changing image stream. There may, however, be two different groups of boys, approximately equal in number: those who prefer the changing image stream, and the others who prefer the non-changing image stream. There appears to be less of a differential in girls, about twice as many who prefer the changing image stream prefer the non-changing image stream. One possible reason for the overall lack of difference may have been due to the difficult nature of the task. Here, I discuss some of the methodological issues that may have contributed to the difficulty. First, there was no familiarization phase, as employed by Quinn and Liben (2008), or habituation phase, as used by Moore and Johnson (2008, 2010). Also, the side of the changing-image stream alternated across trials, which may have added to the difficulty or caused interference for the infants to track differences between the two image streams. This may explain why there was no overall difference in preference for either stream across trials. As mentioned above, we analyzed performance on the first trials only of each task to avoid the issue of carryover. The range of degrees of rotation within each trial may have been too wide to perform mental rotation. Furthermore, the images moved clockwise and counterclockwise randomly within each trial, which could have made the task difficult. Future research should consider modifying these features of the mental rotation task to make it easier for the infant to perform mental rotation and examine potential sex differences in the task. Regarding the preferential looking task, our findings replicated that of a recent study (Alexander et al., 2009): a preference for the doll in boys and girls, and a greater percentage of boys than girls who preferred the truck. A possible reason why a larger proportion of boys than girls preferred the truck is that parents may provide their children with gender-typical activities in infancy (Alexander et al., 2009). The older the boys were, the greater the proportion of time they spent looking at the truck. This may reflect the influence of socialization, since parents encourage gender-typical toy play (Alexander et al., 2009). Perhaps as boys get older they have more exposure to the object. In contrast, age did not relate to doll or truck preference for girls.

There may be something unique about the association between mental rotation and object preference, since the proportion of time spent fixating the truck predicted better mental rotation ability (greater proportion of time to the changing-image stream) in boys but not girls. Furthermore, male age did not account for the relationship between their preference for the changing-image stream and truck. This finding provides a more direct connection for boys between mental rotation and object preference, since age, alone, does not appear to account for the relation.

Some possible explanations may account for the association between the two tasks of mental rotation and object preference in boys. Mental rotation may influence object preference, since an advantage on this task may draw someone to certain toy features that are more conducive to manipulation in space and being seen from various angles. Alternatively, an equally likely possibility, object preference may enhance one's mental rotation ability, since a greater preference for "physical-mechanical" inanimate objects (Connellan et al., 2000, p. 113), such as trucks, may reflect a preference for activities outside of the experimental context that promote mental rotation. Studies on neonates (Connellan et al., 2000) and rhesus monkeys (Hassett et al., 2000) have shown compelling evidence for a strong biological component gravitating males to male-typical objects. In our study, boys' truck preferences increased with age, and since others show that this preference may exists within two days of birth (Connellan et al., 2000), the more common preference later on in infantile development may represent societal influences like parental encouragement of gender-typical play (Pasterski et al., 2005; Fagot, 1978, as cited in Connellan et al., 2000). In other words, object preference may get stronger as a result of socialization.

Another possibility that may account for the association between truck preference and mental rotation in males is another third variable, like testosterone, which could affect mental rotation and object preference, without the two actually interacting (in direct causal way). Since the relationship exists even in young male infants, a force like differential levels of testosterone could be driving the preferences for the changing image stream and truck. The hormone could independently influence mental rotation and object preference, or correlate with mental rotation, which affects object preference, or directly affect object preference, which mediates performance on the mental rotation task. Of course, other (unknown) potential factors may explain the relationship, but we cannot possibly explicate every potential scenario. Future research should consider how to compare testosterone levels to mental rotation ability and object preference to determine the extent to which the three variables are related.

A variety of influences could explain why females did not show the same relationship as males between mental rotation performance and object preference. Seven-year-old girls' speed of mental rotation was associated with higher testosterone levels (Grimshaw et al., 2005), but this relationship may not be found as young as infancy in females because certain experiences may be necessary to develop the skill. For example, Levine et al. (2005) suggested that environmental factors, like exploration and toys that promote spatial skills, are essential to the development of spatial skills in males. Female infants may be less likely to engage in such spatial skill-promoting activities, since they are influenced by parents' "modeling and reinforcement of gender-typical toy play" in experimental and naturalistic settings (e.g. Fagot, 1978; Pasterski et al., 2005, as cited in Alexander et al., 2009, p. 428). Evidence suggests that socialization effects may be occurring as soon as infancy, as shown in female preference for a doll over a truck and males' showing no preference (Alexander et al., 2009). Our study shows this effect in a similar direction, since although boys prefer the doll to the truck, a greater proportion of boys than girls prefer the truck. Perhaps the boys in our study do not replicate Alexander's et al. (2009) finding of boys showing no preference because we measured preference by proportion of looking time, whereas in the former study, they measured preference by number of visual fixations. Number of fixations does not account for individual differences in *duration* of fixations, which is still time spent fixating. It is not likely that female preference for a doll over a truck is determined solely by the environment, since young girls with CAH, who have elevated testosterone levels, prefer male-typical toys despite parental encouragement of female-typical ones (Pasterski, et al., 2005). In this case, it seems that biological influences may be strong enough to overpower environmental influences.

The association between mental rotation and object preference may be modulated by familiarity. Perhaps one is better at mentally rotating objects that one is more familiar with and to which one devotes more time. Hence, it is possible that females did not show a relationship between their performances on the two tasks because of the type of stimuli they were rotating. If someone is better at mentally rotating certain kinds of objects, like inanimate ones, perhaps they have a preference for them. Evidence consistent with this claim is that 7-year-old girls using a rotation strategy were much quicker at mental rotation than boys, and the stimuli were animate figures, black and white bears (Grimshaw et al., 1995). Male infants may have shown an advantage in mental rotation in several studies because the stimuli were inanimate (Quinn & Liben, 2008; Moore & Johnson, 2008; Moore & Johnson, 2010). Additionally, there may have been no association between mental rotation performance and object preference in females because research that uses neuroimaging (i.e., functional Magnetic Resonance Imaging) shows that females rely on different brain mechanisms and strategies when solving questions of mental rotation: mostly parietal activation in males, and mostly parietal activation as well as inferior frontal activation in females (Hugdahl, Thomsen, & Ersland, 2006). Hugdahl and colleagues suggest that “males may be biased towards a coordinate approach, and females biased towards a serial, categorical processing approach” (1575-1583). A coordinate approach involves information about the precise distance between items or parts of one item in metric units. Conversely, a categorical processing approach uses general spatial descriptions (e.g., above or below), irrespective of precise distances.

Future research might consider examining how female infants would compare to males on a mental rotation task comprised of animate stimuli. These studies might also consider testosterone levels as they relate to mental rotation ability and object preference to determine the extent to which the variables are related. It could also be beneficial to have parents complete a toy questionnaire along with a mental rotation and object preference task to examine the relationship between the tasks and experiences with certain objects. Evidence supports a strong biological influence on mental rotation and object preference, but environmental influences show that these two cognitive features are also flexible and can be modified.

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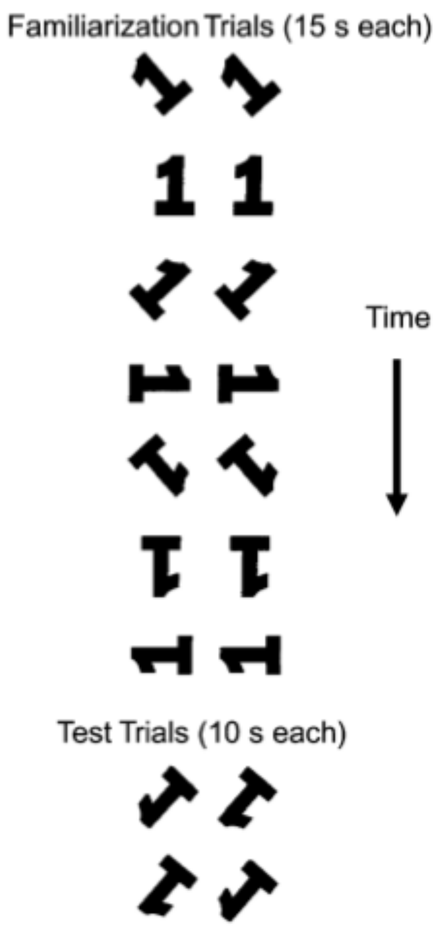

Figure 1. Experimental design used by Quinn and Liben (2008). Infants were familiarized to a 2-dimensional image of the number one ("1") in seven 15-s trials. The image appeared in seven different 45-degree rotations between 0 and 360 degrees that were presented randomly. Two identical copies of each stimulus were presented in each trial. In two 10-s test trials, infants were presented with two images of the number one: not previously seen during familiarization and its mirror image.

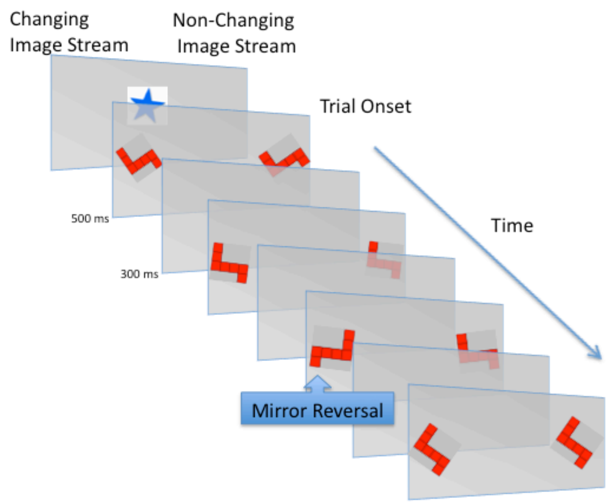

Figure 2. Current study experimental design. Adapted from a numerical change detection paradigm used by Libertus and Brannon (2010), infants were presented with two streams containing static images presented rapidly. One image stream was presented on the far left and the other on the far right. One image stream contained a two-dimensional figure within the picture plane (non-changing image stream). The other image stream was identical except that on every 3rd presentation it was flipped (i.e., appeared as mirror reversal).

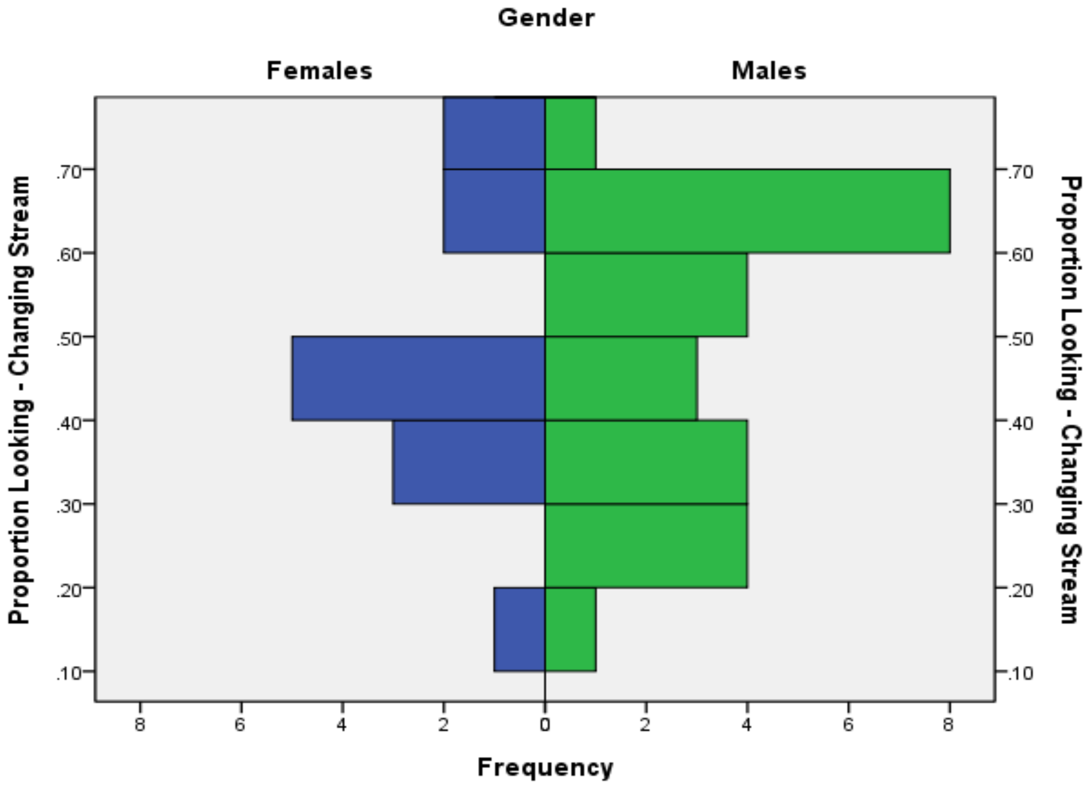

Figure 3. Male and female looking time proportion to changing image stream. This figure presents infants' proportion of time spent looking at changing image stream during first trial of mental rotation task, showing no difference in their proportion of looking time to the changing image stream and non-changing image stream.

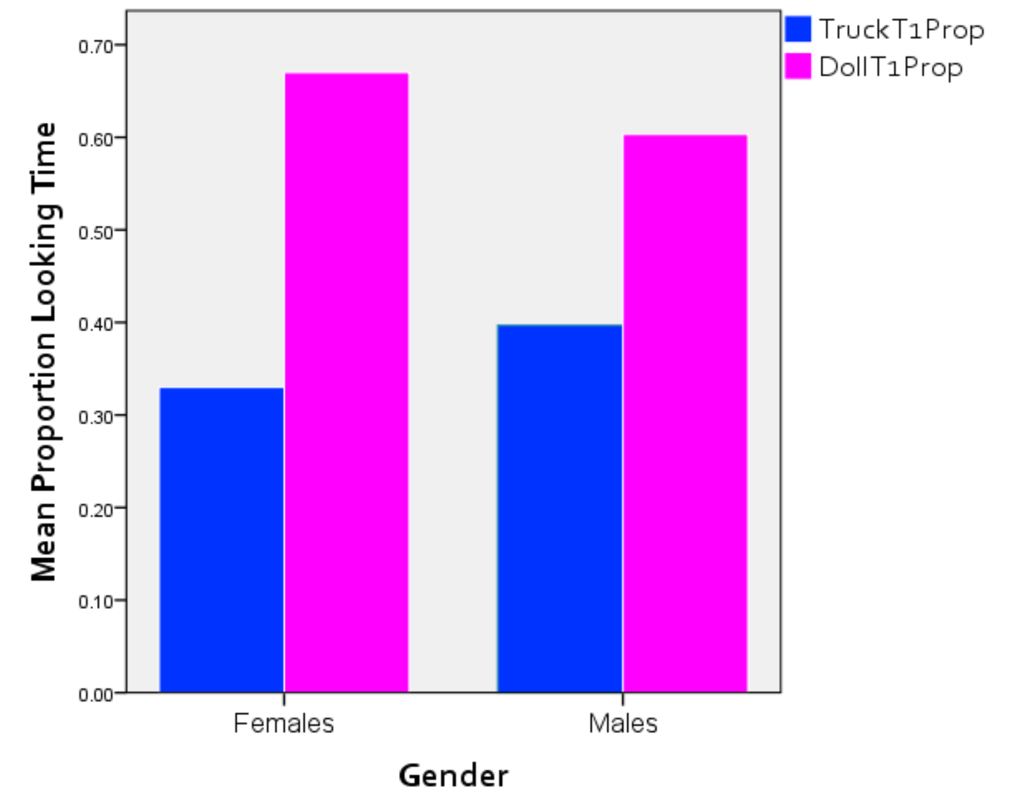

Figure 4. Male and female looking time proportion (mean) to doll and truck. This figure illustrates the mean proportion of looking time in males and females to the doll and truck on the first trial of the object preference task. This shows male and female preference for the doll to the truck.

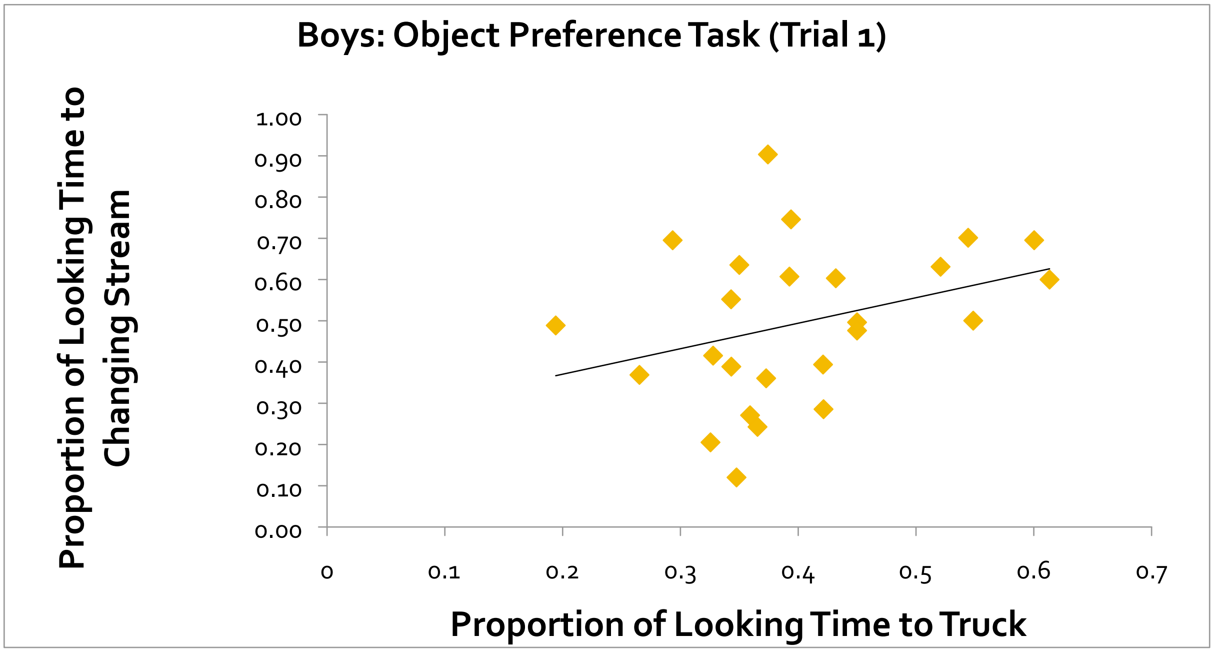

Figure 5. Male looking to changing image stream and truck. Males' proportion of looking time to the truck during the first trial of the object preference task increased with the proportion of looking time to the changing image stream during the first trial of the mental rotation task. This shows an association in males between mental rotation and object preference.

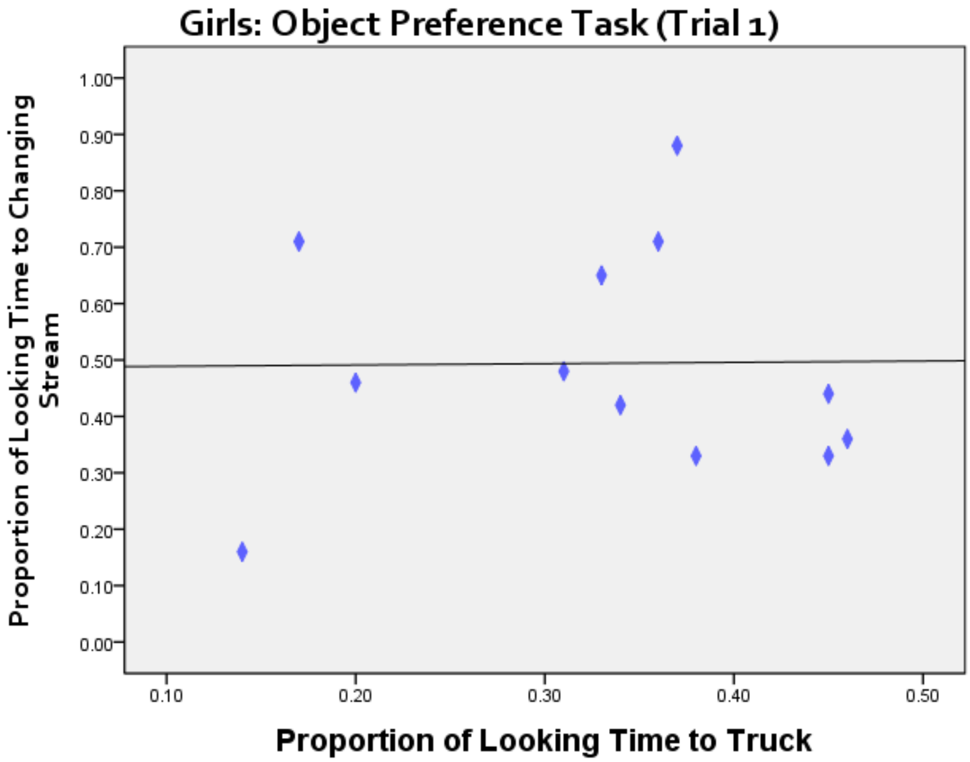

Figure 6. Female looking time to changing image stream and truck. Females' proportion of looking time to the truck during the first trial of the object preference task was not related to the proportion of looking time to the changing image stream during the first trial of the mental rotation task. This does not shows an association in females between mental rotation and object preference on this study's mental rotation task and preferential looking task.