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Crawling is Associated with Mental Rotation Ability by 9-Month-Old Infants

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The present experiment examined whether 9-month-old infants' mental rotation ability was related to their crawling ability. Forty-eight 9-month-old infants were tested; half of them crawled for 7.1 weeks on average. Infants were habituated to a video of a simplified Shepard–Metzler object rotating back and forth through a 240° angle around the longitudinal axis of the object. Infants were tested with videos of the same object rotating through the previously unseen 120° angle and with the mirror image of that display. The results showed that the crawlers looked significantly longer at the mirror object than at the familiar object. The results support the interpretation that crawling experience is associated with 9-month-old infants' mental rotation ability.

Mental rotation refers to the ability to rotate mental representations of two-dimensional and three-dimensional objects (Linn & Petersen, 1985). This ability is crucial even for infants. From soon after birth, infants are confronted with objects in their natural environment that move and rotate. To recognize or grasp a moving object, it is necessary to be able to predict how its orientation will change, which requires the capacity for mental rotation. The question arises about the developmental factors that are relevant for infants' mental rotation ability. Recent studies showed that gender plays a crucial role for infants' ability to mentally rotate objects, indicating an

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advantage for male infants (Moore & Johnson, 2008, 2010; Quinn & Liben, 2008). Other studies demonstrated that experiences with objects through self-produced locomotion like crawling are relevant for infants' visual-cognitive ability in general and in particular for their recognition of object shapes (see Campos et al., 2000 for an overview). These studies leave the question open whether infants' crawling ability is also related to their mental rotation ability. It can be hypothesized that both abilities are linked with each other because self-produced locomotion, like crawling, provides infants with the opportunity to view objects in different perspectives and to learn to understand the different rotations of a target object as belonging to the same object. The present experiment, therefore, aimed to investigate if crawling is related to infants' mental rotation ability.

Influence of gender on mental rotation ability

Previous research has shown that there are robust gender differences in mental rotation ability in adults (Linn & Petersen, 1985), although the effect depends on the nature of the stimulus (Voyer, Voyer, & Bryden, 1995) and whether data on accuracy or speed are gathered (Jansen-Osmann & Heil, 2007). The largest gender differences have been found using Shepard and Metzler's (1971) classic task, in which subjects view a two-dimensional image of a three-dimensional object and then distinguish between a novel view of the same object and its mirror image.

Earlier work on the mental rotation ability of infants did not find any gender differences (e.g., Hespos & Rochat, 1997; Rochat & Hespos, 1996). In these studies, infants as young as 4 months of age were required to extrapolate the trajectory of a moving object, anticipate its probable future orientation, and discriminate this future orientation from an improbable orientation. Infants succeeded on this task. But, the task was quite different from the mental rotation task Shepard and Metzler used with adults; instead of a mirror image, the improbable orientation was a 180° rotation in the same plane as the future orientation.

Recently, however, gender differences in mental rotation ability have been found in early infancy. Quinn and Liben (2008) and Moore and Johnson (2008, 2010) conducted studies with 3- to 4-month-old and 3- and 5-month-old infants, respectively, using tasks more closely related to the Shepard and Metzler procedures. Quinn and Liben familiarized 3- to 4-month-old infants with a series of two-dimensional images of the numeral "1" and then preference-tested them with a novel orientation rotation of the numeral paired with its mirror image. They found that boys displayed a novelty preference for the mirror image, but girls did not; this reveals the early emergence of a gender difference in infants' ability to mentally rotate an object.

Moore and Johnson obtained similar results with 3- and 5-month-old infants. In contrast to Quinn and Liben, they used a simplified, three-dimensional Shepard–Metzler object and habituated the infants to this object as it rotated through a 240° angle. In test trials, infants saw the familiar object or its mirror image rotating through a previously unseen 120° angle. Only the boys recognized the familiar object in its new perspective, providing further evidence for a gender difference in the ability to mentally rotate an object in three-dimensional space.

Influence of motor experience on mental rotation ability

Previous research has demonstrated that a short-term motor training or advanced motor development are also relevant for mental rotation ability. In 10- to 11-year-old children, Wiedenbauer and Jansen-Osmann (2008) found that manual rotation training can improve the mental rotation performance. In a training phase, children were asked to manually rotate a drawing of an animal depicted on a computer screen into the orientation of a standard drawing of the animal. Input device for rotating the drawings of the animals was a joystick. The training enhanced children's mental rotation ability, and the training effect was not limited to trained stimuli. In another study, Jansen and Heil (2010) showed that mental rotation ability was related to motor development in 5- to 6-year-old children. Children performed a standardized motor test, a paper–pencil mental rotation test, and a non-verbal reasoning test. A multiple regression analysis revealed that non-verbal reasoning and motor abilities were significant and independent predictors of children's mental rotation performance.

Studies on the influence of motor experience on mental rotation ability have focused on children and not on infants. Relevant infant studies rather focused on the relation between motor experience, such as crawling, and infants' spatial memory for objects. Kermoian and Campos (1988), and more recently Clearfield (2004), found that infants with more crawling or locomotor experience were more successful in searching for hidden objects.

But, determining the contribution of motor experience to mental rotation ability of infants is also worthwhile because motor experiences like manual exploration of objects and self-produced locomotion, such as crawling, may be also related to infants' mental rotation ability. This could be because these activities provide infants with views of the same object from different perspectives. Mash, Arterberry, and Bornstein (2007) have shown that providing infants with views of the same object from different perspectives is crucial for their recognition of an object in an unfamiliar orientation, an ability which is also necessary for mental object rotation. Soska, Adolph, and Johnson (2010) have demonstrated infants' motor skills, such as sitting and manual object exploration, to be related to their ability to complete three-dimensional objects, an ability also relevant for mental rotation ability. On the other hand, Campos, Bertenthal, and Benson (1980) studied the relation between infants' crawling experience, which naturally provides infants with different object views, and their ability to recognize different shapes of objects independently of orientation, size, and color; they found that the performance of infants who were crawling was significantly better than that of non-crawling infants. We, therefore, assume that motor skills, such as crawling and manual object exploration, which provide infants with the opportunity to view objects in different perspectives and to enhance detection of object invariance, are associated with infants' mental rotation ability. In this study, we focused on crawling as one of the relevant factors for infants' mental rotation ability.

METHOD

Participants

Participants included 22 female and 26 male full-term healthy infants (mean age: 9 months, 3 days; range: 9 months – 9 months, 7 days). To obtain information about infants' crawling ability we had sent a so-called movement calendar (constructed by the authors) to the parents 4 weeks before testing the baby in the lab. In the calendar, the parents were asked to report when their baby started to be capable of crawling, defined as moving in a prone position on hand-and-knees for at least 2 meters. In case of uncertainties, we discussed the entries with the parents. Bodnarchuk and Eaton (2004) had shown that parents provide reliable reports of their infants' attainment of motor milestones, including crawling. Twenty-four of the infants (13 boys and 11 girls) were crawlers for 7.1 weeks on average, at least for two weeks. Two infants were excluded from the study because they were able to crawl for only 7 and 8 days. None of the infants in the non-crawling group were able to crawl. All infants were from middle-class families.

Stimuli

The stimulus images of Moore and Johnson (2008, 2010) were used. They were simplified Shepard–Metzler objects, an L-object and an R-object, and are shown in Figure 1.

All faces of the objects were medium red when viewed from above, dark red from below, orange from the front, ocher from the back, yellow from the right, and gold from the left (see Figure 1). In contrast to Moore and Johnson, we used relatively similar colors for the different surfaces of the

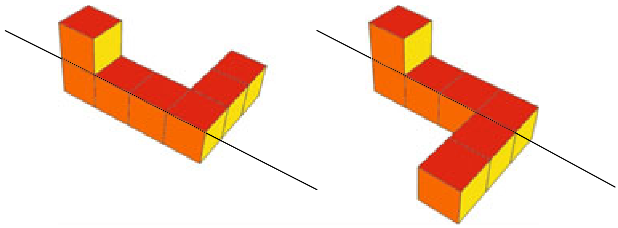

Figure 1 Images of the simplified Shepard–Metzler objects, the L-object and its mirror image, the R-object. The lines represent the longitudinal rotation axis of the objects. The images were presented to the infants without the lines.

objects to maintain the integrity of the L- or R-object as a whole. The maximum vertical and horizontal dimensions of the objects during presentation of the images were 16° and 12° of visual angle, respectively.

We constructed habituation and test videos of these objects according to the stimuli videos used by Moore and Johnson (2008, 2010). Each habituation video was composed of a series of images of the same object (L- or R-object) rotated an additional 2° around the longitudinal axis of the object, which differed 60° from the vertical axis (see Figure 1). This series of images appeared as an object rotating at 52° 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.

The videos of the L- and R-objects used for the test videos continued the rotation of the L- and R-objects, respectively, through the previously unseen 120° of arc. Each of the images constituting a test video represented the habituation object rotating an additional 2° around the longitudinal axis of the object. A habituation video and its corresponding test video together represented a complete 360° turn around the longitudinal axis. The objects in the test videos continuously rotated back and forth between the starting points and the maximum extents of their rotations. No orientation of either habituation stimulus was identical to any orientation of either test stimulus.

Apparatus

The experiment was conducted in a rectangular cabin with one open side that was designed to accommodate a caregiver sitting on a chair with the child on her lap. Each infant was seated on the caregiver's lap at a distance of 60 cm from the computer monitor screen displaying the stimuli, which was inserted into the rear wall of the cabin. To prevent parents from influencing their babies' looking times, they were asked to keep their eyes closed and to refrain from talking for the duration of the experiment. The entire session was recorded on a video cassette recorder, using a low-light video camera attached to a peephole in the back of the cabin.

Procedure

Each infant was tested individually; sessions consisted of a habituation and a test phase. Infants were randomly assigned to the L- or R-habituation videos. In the habituation phase, infants were presented the habituation video portraying the L- or R-object, respectively. Trials were accompanied by an auditory attention-getter and began when infants looked at the monitor. Looking time to the object was recorded online by the experimenter by pressing a button. The trial ended either 2 sec after the experimenter released the button to indicate that the infant was no longer fixating the display or after 60 sec. If the infant returned attention to the video in the 2-sec interval, the trial continued. The habituation phase ended when the average time fixating the habituation video declined to 50% of the average time of fixation in the first three habituation trials and maintained across three consecutive trials or when a maximum of 12 habituation trials was presented. After habituation, a series of six test videos (3× test video L-object and test video R-object) was presented. The order of the presentation of the test videos was counterbalanced across the trials.

Trained observers who were naïve to the hypotheses under investigation recorded looking times related to the stimuli from the videotapes of the sessions. Inter-observer reliability of the experimenter and the off-line observers exceeded 0.9.

RESULTS

Preliminary analyses examining the effect of habituation with the L- versus R-object and the order of test stimulus presentation on the looking times to the familiar versus novel test stimulus revealed no reliable main effects or interactions; therefore, data were collapsed across these variables for the following analyses.

A 2 (test stimuli: familiar, novel) × 2 (crawling: yes, no) × 2 (gender: male, female) ANOVA revealed two significant effects, a main effect of crawling ($F(1, 44) = 4.74$, $p < .03$, $\eta^2 = .1$) and a test trial × crawling interaction ($F(1, 44) = 4.49$, $p < .04$, $\eta^2 = .09$). The main effect of crawling showed that the crawlers had significantly longer mean looking times in the test phase (over familiar and novel test stimuli) than the non-crawlers, $t(46) = 2.28$, $p < .03$, two-tailed (crawlers: $M = 13.67$ sec ($SD = 6.84$ sec), non-crawlers: $M = 9.73$ sec ($SD = 4.95$ sec). The test stimuli

× crawling interaction revealed that the crawling infants looked longer to the novel object than to the familiar object (novel object: $M = 7.91$ sec [$SD = 5.03$ sec], familiar objects: $M = 5.76$ [$SD = 3.53$ sec]), whereas the non-crawling infants treated the test stimuli relatively similar (novel object: $M = 4.47$ sec [$SD = 2.43$ sec], familiar object: $M = 5.26$ sec [$SD = 3.62$ sec]). Post-hoc t-tests revealed that crawlers looked significantly longer at the novel stimulus than non-crawlers, $t(46) = 3.01$, $p < .004$, and that the crawlers' looking time differences between looking at the novel stimulus and the familiar stimulus significantly exceeded the corresponding looking time differences of the non-crawlers, $t(46) = 2.21$, $p < .03$, see Figure 2.

Accumulated looking times and number of trials in the habituation phase did not differ with respect to infants' crawling ability and gender.

DISCUSSION

The present study revealed that 9-month-old infants who were able to crawl were more successful in performing the mental rotation task than non-crawling infants of the same age. After habituation with different dynamically presented orientations of an object, only crawling infants generalized from the habituation images to the familiar object in a new orientation and exhibited longer looking times to the mirror image of the object. In contrast, non-crawling infants did not distinguish between the familiar object in a novel orientation and the mirror image of the object.

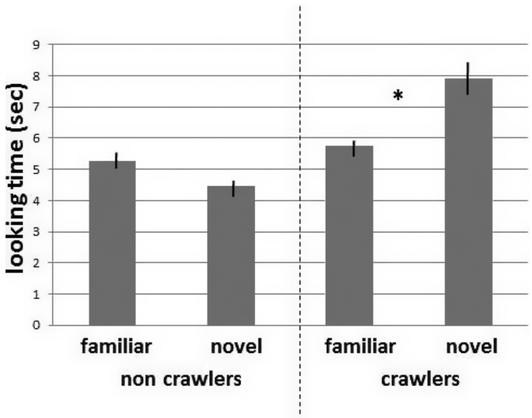

Figure 2 Nine-month-olds' mean looking times at familiar and novel test stimuli. Error bars indicate standard error of the mean, and an asterisk indicates statistical significance, $p < .04$.

Our findings are in line with those of related studies that emphasize the interaction between motor skills and visual–cognitive abilities (e.g., Campos et al., 2000; Jansen & Heil, 2010; Wiedenbauer & Jansen-Osmann, 2008). In particular, they are consistent with the results of Campos et al. (1980), who found that crawling was significantly related to the improvement in the object recognition abilities of 7.5-month-old infants.

Another study by Campos, Anderson, and Telzrow (2009) found such a link in infants with spina bifida. They showed that their onset of crawling was related to an enhanced ability in a two-position object permanence manual search task and a task assessing the infant's following of the point/-gaze gesture of the experimenter. Also, Clearfield (2004) found that normal developing infants with more crawling or locomotor experience were more successful in searching for hidden objects. Our findings also are congruent with the finding that, for younger infants, motor skills, such as sitting and manual object exploration, are related to performance on other tasks involving spatial cognition, such as the ability to complete three-dimensional objects (Soska et al., 2010).

Our findings suggest that non-crawling infants at 9 months of age were not able to mentally rotate the objects, a finding which is on the first glance surprising because younger male infants in previous studies, the 3- to 5-month-old boys (Moore & Johnson, 2008, 2010), showed this ability. Although the studies used a comparable research design, it could be that slight methodological differences between the studies are responsible for the different findings. In contrast to Moore and Johnson, we used relatively similar colors for the different surfaces of the objects to maintain the integrity of the L- or R-object as a whole. But, the similar colors of the different surfaces in our study made it more difficult to encode the different positions of the rotating object. Another methodological difference between the studies refers to the rotation axis of the stimuli objects. In Moore and Johnson's study, the stimulus object rotated around the vertical axis while in our study the stimulus object rotated around the longitudinal axis of the object, which differed 60° from the vertical axis. It could be that the mental rotation around the vertical axis is easier for young infants because such vertical object rotations seem to be more common in the natural environment than mental rotation around the longitudinal axis as used in our study. We assume that such methodological differences could have caused the apparent regression in mental rotation ability in our study.

The better mental rotational performance of the crawling infants in our study might be explained by their everyday experience with the objects they encountered while crawling, which provided them with the opportunity to view objects in different perspectives. Crawling around a piece of furniture, for example, permits the infant to detect the invariant properties of the furniture and consequently recognize it from a novel perspective. Non-crawling infants would not have had this experience.

It is a limitation of the present study that our research design does not allow a firm conclusion how infants processed the test stimuli, whether they in fact mentally rotated the test stimuli or whether they used a process such as structural description that enables matching in the test phase without rotation. An empirical answer to this question needs to be given in future work.

It will also be important for future research on infants' mental rotation ability to determine precisely how crawling experience is related to mental rotation ability. It could be, for example, that crawling infants are generally more motivated to explore objects because they are better able to obtain access to objects in their environment, which provides them with more opportunities to manipulate objects. In this view, it is their experience with object manipulation rather than crawling that is the basis for mental rotation ability. On the other hand, it is also conceivable that younger non-crawling infants' experience with different viewpoints of an object owing to their object manipulation skills needs to await the onset of crawling and navigating in three-dimensional space to become effective for mental rotation ability. It is a task for future studies to exactly specify the relevance of these factors for infants' mental rotation ability.

Another limitation of the present study is that age was held constant in the research design, and infants were classified into those with and without crawling experience. As a result, it is possible that a third factor contributes to the relation between acquisition of crawling and the mental rotation ability. It could be that the crawling infants are generally more advanced than the non-crawling infants and would display performance advantages on a wide variety of tasks. But, the data of the current study showed that crawlers and non-crawlers showed similar information processing measures within the habituation phase, like accumulated looking times and number of trials. But it is an open question whether the crawlers are ahead of the non-crawlers in other variables. An appropriate design to overcome this limitation is an experimental design in which pre-locomotor infants are randomly assigned to receive some type of self-produced locomotor experience (Uchiyama et al., 2008).

All in all, the present findings support the interpretation that crawling experience is associated with 9-month-old infants' mental rotation ability.

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