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Developmental Changes in the Interference of Motor Processes with Mental Rotation

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Abstract

Preceding studies with adult human subjects revealed that motor activities can influence mental rotation of body parts (e.g., hands) and abstract shapes. In this study, we investigated the influence of a rotational hand movement on mental rotation performance from a developmental perspective. Five-, eight-, and eleven-year-olds and adults were given a mental rotation task while they simultaneously rotated their hand (guided by a handle) about the same axis. The direction of the manual rotation was either compatible or incompatible with the direction of the mental rotation. As a baseline, children and adults performed the mental rotation task without concurrent hand movement. Response times increased with increasing stimulus orientation angle, indicating that subjects of all age groups used mental rotation to perform the task. Older age groups showed shorter response times. A differential influence of the direction of manual rotation on mental rotation was found for five-year-olds and eight-year-olds, but not for eleven-year-olds and adults. These results suggest that the ability to dissociate motor from visual mental processes increases with age.

Keywords: cognitive development, children, imagery, mental rotation, motor processes

Introduction

Kinetic imagery in children

In research on cognitive development, imagery abilities have been recognized as a highly important competence (Piaget & Inhelder, 1971). Despite this initial interest, few studies have investigated imagery in children. Therefore, to date there is little evidence about how imagery abilities develop and which basic processes are involved. Piaget and Inhelder (1971) proposed a basic distinction between static and kinetic mental images. They suggested that imagery in the preoperational child remains essentially static, and therefore children are neither able to represent movements nor anticipate the results of movements or spatial transformations. According to Piaget and Inhelder (1971), it is not until the concrete operational stage, at about 7 to 8 years of age, that the child is able to use kinetic imagery, which is to represent movements of objects in space, manipulate mental images, or anticipate the outcome of events.

However, Piaget's methods, which largely relied on drawings, search tasks, and verbal reports, have been criticized repeatedly (e.g., Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990; Marmor 1975), mainly because of the potential confound of performance and competence. Seeking more objective and quantitative measures, more recent developmental studies on mental imagery adopted a task developed by Shepard and his colleagues (Cooper & Shepard, 1973; Shepard & Metzler, 1971). In this paradigm, the subject is required to discriminate whether a rotated figure is exactly the same or a mirror image of the original upright figure. Shepard and Metzler (1971) demonstrated that the time adults required making this discrimination increased linearly with the angular difference in rotation. This suggests that the adults had mentally rotated one form into congruence with the other.

Mental rotation studies with children demonstrated (Kosslyn et al., 1990; Marmor, 1975) that participants as young as 5 years old use mental rotation to solve the task, (i.e., their response times showed a linear increase with angular disparity of the two stimuli), but they do so at a

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slower speed (i.e., the younger the children, the longer it takes them to mentally rotate the stimuli). In a study that compared familiar with unfamiliar stimuli, Kail, Pellegrino and Carter (1980) found that the time required to encode and compare the stimuli decreased with age, and that even after 8 years of age, there was still a notable increase in the speed of mental rotation. However, some researchers have reported age invariance in rotation rates for children aged 9 years and older (Childs & Polich, 1979).

In most studies mentioned above, children were instructed or trained to apply a mental rotation strategy to solve the task. However, preschoolers have been found to use mental rotation spontaneously. Marmor (1977) tested 4- and 5-year-olds for an effect of training to use a mental rotation strategy, applied prior to the test. This study revealed no difference in performance between trained and untrained children. Moreover, no interaction of training and age was found. These findings suggest that 4- and 5-year-olds are able to use and evoke kinetic imagery. Assessing response time patterns and verbal reports, Estes (1998) showed that 6-year-olds were comparable to adults, both in their spontaneous use and subjective awareness of mental rotation.

In short, developmental research on mental rotation has shown that the capability, spontaneous usage, and awareness of a mental rotation strategy can be found in children as young as 4 or 5 years of age, and that the speed of mental rotation increases with age.

Motor processes and kinetic imagery

Results from mental rotation studies with adult participants provided evidence for the assumption that imagery and perception share some of the same underlying processes (Corballis & McLaren, 1982; Jolicoeur & Cavanagh, 1992). This was further supported by neuroimaging studies showing that partly the same brain areas associated with mental imagery are also active during perception (e.g. Kosslyn, Thompson, Kim, & Alpert, 1995). Yet in other studies, some researchers found evidence for increased difficulty to mentally rotate pictures of hands showing physically impossible or awkward positions (Cooper & Shepard, 1975; Parsons 1987, 1994; Sekiyama, 1982) and activation in motor areas during mental rotation of body parts (e.g., Parsons, Fox, Downs, Glass, Hirsch, Martin, Jerabek, & Lancaster, 1995).

These findings led to the assumption that mental rotation also engages processes other than those known to be associated with the perception of real or apparent visual motion, and that processes of action planning are probably involved (Jolicoeur & Cavanagh, 1992; Kosslyn, 1994; Wohlschläger & Wohlschläger, 1998). For example, Wohlschläger and Wohlschläger (1998) found that mental rotation of an object performed in the same direction as a concurrent manual rotation (about the same axis) is performed faster compared to when the manual and mental rotation are opposite in direction. Similarly, Wexler, Kosslyn and Berthoz (1998) reported shorter response times and fewer errors when the directions of mental object rotation and manual rotation where compatible. Their motor task modified the inverted V-shaped curve representing response times of mental rotation (from 0° to 360°); in some cases the location of the minimum shifted toward the direction of the manual rotation.

Motor processes and kinetic imagery in children

Despite compelling evidence showing that motor activity interferes with mental transformations in a direction specific manner, still relatively little is known about this interference in children. Rieser, Garing, and Young (1994) showed that walking without vision facilitates children's ability to imagine a spatial layout from another perspective. Similarly, Black and Schwartz (1996) showed that physically turning a cup facilitated the ability to predict the point at which imaginary water inside the cup would reach the rim. More recently, Funk, Brugger and Wilkening (in press), demonstrated that the actual position of participants' hands can influence how fast children distinguish rotated right and left hands. However, it still remains largely unclear whether or to what extent motor processes influence children's performance in mental imagery.

The present experiment was conducted with children and adults and employed a dual task paradigm similar to Wohlschläger and Wohlschläger (1998) and Wexler et al. (1998). We pursued the following research questions: a) does manual rotation interfere with mental rotation, b) does the direction of manual rotation exert a differential effect on mental rotation, and most importantly c) if there are any effects of manual rotation on mental rotation, do they develop with age?

Method

Participants

A total of 84 participants were tested. Data of four 5-year-olds were excluded from analysis, due to a lack of attention and compliance to the task (disrupting manual rotation). The remaining 80 participants included four age groups, each with 20 participants: 5-year-olds (mean age 5;7, range 5;2 to 5;11, male: 11, female: 9), 8-year-olds (mean age 8;6, range 8;0 to 8;11, male: 11, female: 9), 11-year-olds (mean age 11;5, range 11;0 to 11;11, male: 7, female: 13) and adults (mean age 37;4, range 23;10 to 68;4, male: 10, female: 10). Children were recruited from different primary schools in the region of Zürich, Switzerland. Adult participants were personal acquaintances of one of the authors. Participants had normal or corrected to normal vision. Only right-handed people were recruited.

Apparatus

The experimental apparatus consisted of three parts: a laptop computer, a rotatable wheel with a handle, and a response pad. Participants were seated at a table. The laptop was positioned on a table, in front of the participant.

The wheel and the response pad were mounted on a T-shaped wooden construction that could be fixed to any table, ensuring a constant distance from the wheel to the response pad (see Figure 1 for a schematic drawing of the apparatus). This construction protruded the table's top by 19 cm, occluding the wheel, which was attached 12 cm below.

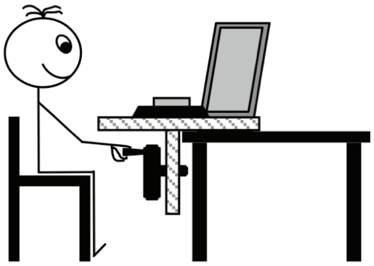

Figure 1: Schematic drawing of the apparatus and experimental situation.

This protrusion prevented participants from seeing their right hand operating the wheel. The response pad was positioned above the wheel, mounted visibly on top of the protrusion. The height of the participant's chair was adjustable, so that each child could comfortably reach the handle of the wheel, and from there switch to the answering pad on top of the construction, without having to move the upper part of their body. The wheel could be turned in the participants' frontal plane only in either direction. The handle was perpendicular to the wheel, 5 cm off the center, and could be turned without loosening the grip

A "Cedrus Response Pad (RB 520)" was used for measuring the responses. Two response buttons were enlarged by black or white 4 x 8 cm cardboard pieces, so that they could be pressed easily and quickly. The distance between the two response buttons was 4.5 cm. The experimenter operated one small button to proceed to the next trial, and remained seated to the right of the participant throughout the entire session. From this viewpoint she could see the participants' face, their hands at the wheel, and the computer screen (corresponding approximately to the viewpoint in Figure 1).

Stimuli

The stimuli were presented on the computer screen, a 14-inch TFT display, with a resolution of 1400 x 1050 pixels, True Colour, with an ATI graphic board. The program used was Superlab Pro by Cedrus.

Two different two-dimensional stimuli were presented simultaneously. In the present experiment, however, it was crucially important to control for the direction in which the stimulus was rotated mentally. Therefore, figure-ground pairs (like a puzzle-game, see Figure 2) were used rather than two similar figures. This paradigm ensured that participants rotated the small figure, and thus ruled out any ambiguity in the direction of mental rotation.

Figure 2: Four examples of figure-ground pairs as they appeared on the computer screen. In examples A (+45°) and C (0°), the figure would fit into the ground after an appropriate rotation; in B (-90°) and D (+135°) the figure would not match the holes.

The larger stimulus, the "ground", was 5 cm high and spanned the whole screen width at the lower margin of the display. In the very middle at the upper rim of this ground, there were two holes. One hole had a square shape and one a round shape. The small stimulus, the "figure", was presented centered right above these holes, in the upper part of the display. The figure had a size of 6.5 cm by 7 cm, and on its lower end (in the upright position) one half was square, the other half was round. When moved down on the display, the round and square parts of the small figure would perfectly fit into the round and square holes in the ground. We presented mirror versions of both the figure and the ground, which resulted in 4 figure-ground combinations, of which two would match and two would not match.

The figures were always presented in the same position on the screen but varied in eight different orientations: 0°, +45°, +90°, +135°, 180°, -135°, -90°, -45°. In the upright orientation (0°), no mental rotation was required to solve the task. A positive angle corresponded to stimuli rotated in clockwise direction; a negative angle corresponded to stimuli rotated in counterclockwise direction. There were a total of 32 stimulus pairs: 2 (figure version) x 2 (match) x 8 (orientation angle). Each stimulus pair was presented twice.

Procedure

Children were tested at their school or kindergarten in a separate room. Adults were tested at home. The experiment consisted of a familiarization phase, a training phase, and an experimental phase and lasted between 15 and 40 minutes.

In a familiarization phase, the mental rotation task was explained with two cardboard pieces that were magnified replications of the stimuli on the computer screen. The pieces were laid out flat on the table in front of the participant, in the same spatial arrangement in which they later appeared on the computer screen. The experimenter explained that the figure could be turned flat on the table, but not lifted or flipped over. The first trials could be solved by physically turning the figure with the hands. Then participants were asked to imagine what the figure would look like if it were rotated, and thus trying to find out whether it actually fits into the holes. At least five trials were presented to each participant, using the four possible figure-ground combinations. As soon as a participant had solved three subsequent trials correctly, the training phase began.

In the training phase, stimuli were presented on the computer screen. Participants were asked to hold the handle of the wheel with their right hand without turning it, and not to let go until they found out the answer. At this point, they were supposed to press the correct button on the response pad as quickly as possible. Participants had to hit the left (white) button for matches, the right (black) button for mismatches. Feedback was given after each practice trial (but not for the experimental trials later): for correct trials a smiley face appeared on the screen, for incorrect trials a frowney face. Before the next trial began, a cartoon figure appeared centered on the computer screen to attract participants' attention. The experimenter would then trigger the following trial by pushing a button, as soon as the participant's eyes were centered on the computer screen; the stimulus would appear after 750 ms. A predetermined order of 12 trails was presented (0°, +22°, -67°, 180°, +112°, -157°, -22°, 180°, +67°, -112°, +157°, 0°). The angles used in the training differed from the angles used in the experiment proper.

The experimental phase consisted in four blocks of 32 trials. The first block (A) was a mental rotation task without rotating the handle. The participant's hand rested on the handle; this was done to keep the distance to the response pad comparable with the second (B) and third (B) block, in which the handle was rotated manually. The fourth block (A) was again without manual rotation. This ABBA-design provided the same amount of trials with and without rotation, while equally distributing possible training effects. Within each block, trials were presented in random order.

After the first block (A) participants were briefly trained to turn the wheel continuously at a speed of about 2.5 seconds per cycle. In the following experimental trials, participants turned the wheel for about one cycle, before the experimenter would initialize the next trial. Whenever the rotation speed changed considerably, the experimenter asked the participants to turn faster or slower.

Half of the participants were instructed to rotate the wheel clockwise; the other half rotated the wheel counterclockwise. For participants in the clockwise group, the positive stimulus orientations, +45°, +90°, and +135° resulted in incompatible manual and mental rotations, the negative orientations, -135°, -90°, and -45° resulted in compatible rotations (see Figure 3). Conversely, for participants in the counterclockwise group, positive stimulus orientations led to compatible rotations and negative ones to incompatible rotations. Thus, for each participant 24 trials were compatible, 24 trials were incompatible, and 16 trials were neutral (0° and 180°).

Results

Response times

Response times of all correct trials were submitted to an analysis of variance (ANOVA), with the within-subject factors stimulus orientation (0º, +45º, +90º, +135º, 180°, -135°, -90°, -45°), manual rotation (with or without) and measurement repetition, as well as with the between-subjects factor age.

Response times are illustrated in the upper part of Figure 4. A significant age effect was found, $F(3, 64) = 62.83$, $p < .001$, $\eta^2 = .75$, response times increased with decreasing age. Response times also increased with increasing angle of stimulus orientation, $F(4, 258) = 44.51$, $p < .001$, $\eta^2 = .41$. This was true for all age groups (adults: $F(2, 29) = 24.78$, $p < .001$, $\eta^2 = .61$, 11-year-olds: $F(2, 33) = 24.16$, $p < .001$, $\eta^2 = .60$, 8-year-olds: $F(3, 55) = 23.51$, $p < .001$, $\eta^2 = .60$, 5-year-olds: $F(4, 60) = 15.63$, $p < .001$, $\eta^2 = .49$).

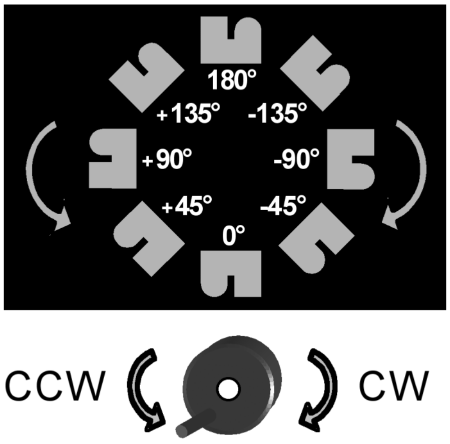

Figure 3: Stimulus orientations: positive orientations are compatible to counterclockwise manual rotation; negative orientations are compatible to clockwise manual rotation.

Additionally, the variables age and stimulus orientation interacted, $F(12, 258) = 7.58$, $p <.001$, $\eta^2 = .26$. The increase of response time over orientation angle was larger the younger the participants were. Response times were shorter when the task was performed without manual rotation, $F(1, 64) = 17.56$, $p <.001$, $\eta^2 = .22$. There was also an interaction between manual rotation (with or without) and the factor age, $F(3, 64) = 4.15$, $p < .01$, $\eta^2 = .16$. The difference in response times between the conditions with and without manual rotation decreased with age. No effect of measurement repetition was found, $F < 1$.

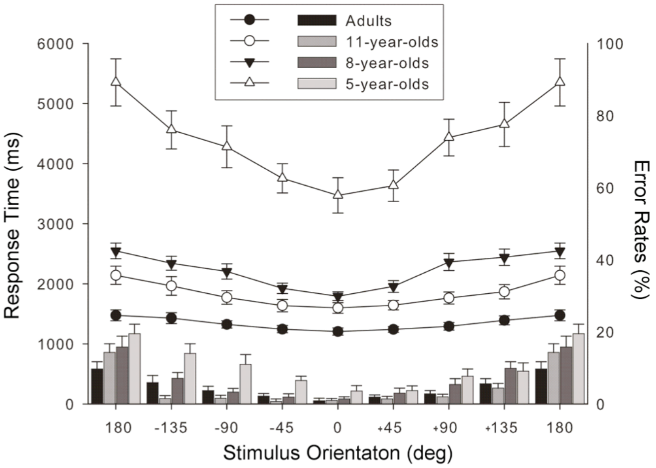

Figure 4: Means and standard errors of response times (upper part and left y-axis) and error rates (lower part and right y-axis) for each stimulus orientation and age group.

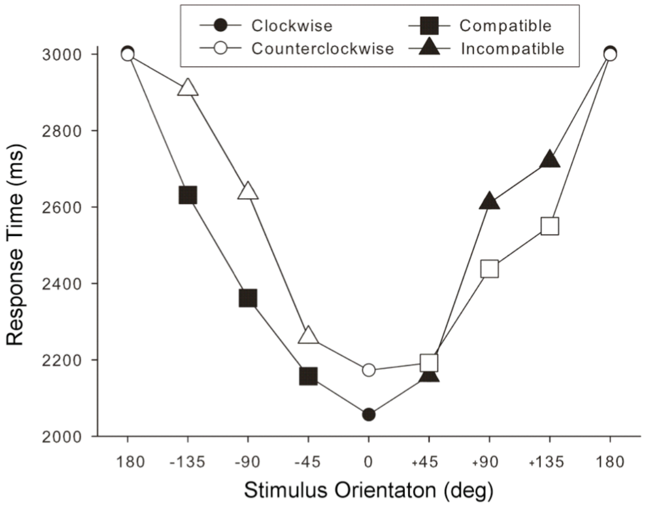

Figure 5: Means of the response times, averaged over age groups. Filled symbols indicate clockwise manual rotation; empty symbols indicate counterclockwise manual rotations. Squares indicate compatible mental and manual rotation; triangles indicate incompatible mental and manual rotation.

Compatible versus incompatible rotations Figure 5 shows that (with only one exception) participants produced longer response times for incompatible trials (triangles) than compatible trials (squares). In order to analyze the influence of compatible and incompatible manual rotation on mental rotation, negative and positive stimulus orientation angles were pooled into compatible and incompatible angles. Response times of the angles 0º and 180º were excluded from data analysis. Response times were submitted to an ANOVA with the within-subject factors stimulus orientation (45º, 90º, 135º), compatibility (compatible vs. incompatible manual rotation) and the between-subjects factor age. A main effect of compatibility was found, $F(1, 64) = 14.26$, $p < .001$, $\eta^2 = .18$. Response times were shorter with compatible manual rotations than with incompatible manual rotations. There was a significant age by compatibility interaction, $F(3, 64) = 3.86$, $p < .05$, $\eta^2 = .15$, showing that the difference of response times between the compatible and the incompatible condition decreased with age.

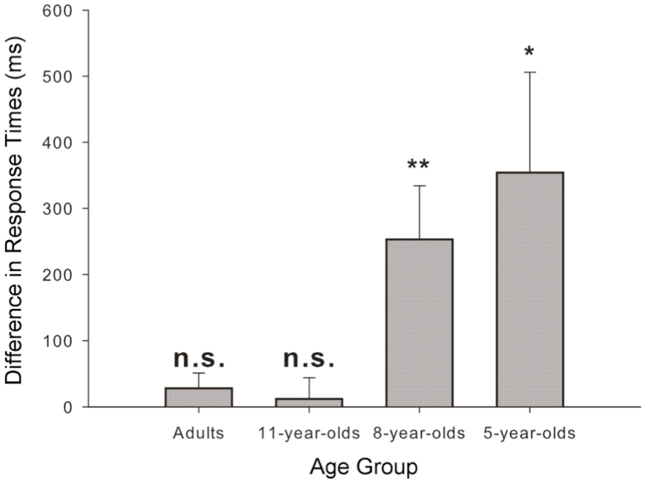

Figure 6: Means and standard errors of the differences in response times between incompatible mental and manual rotation and compatible mental and manual rotation.

A separate analysis of each age group showed that the effect of compatibility could only be found in the two younger age groups (5-year-olds: $F(1, 16) = 6.15$, $p < .05$, $\eta^2 = .28$, 8-year-olds: $F(1, 16) = 9.38$, $p < .01$, $\eta^2 = .37$, see Figure 6). The response times of the 11-year-olds and the adults were also faster with compatible manual rotation but these differences did not reach significance (11-year-olds: $F < 1$, adults: $F(1, 16) = 1.37$, $p = .26$, $\eta^2 = .08$).

Error rates

Overall, participants answered incorrectly in a total of 5.7 % of the trials. Error rates are displayed in the lower part of Figure 4. The errors of all participants were submitted to an ANOVA with the within-subject factors stimulus orientation (0º, +45º, +90º, +135º, 180°, -135°, -90°, -45°) and manual rotation (with or without) and the between-subjects factor age. Error rates increased with increasing angle of mental rotation, $F(5, 301) = 30.84$, $p < .001$, $\eta^2 = .33$. The largest amount of errors was found with a stimulus orientation angle of 180º. No effect of manual rotation was found, $F(1, 64) = 3.72$, $p = .06$, $\eta^2 = .06$. Participants produced an equal amount of errors in the condition with manual rotation as in the condition without manual rotation. The between-subjects factor age was significant, $F(3, 64) = 12.57$, $p < .001$, $\eta^2 = .37$. The older participants were, the less errors they produced.

Compatible versus incompatible rotations Similar to the response times, error rates were analyzed with respect to compatible and incompatible manual rotations. An ANOVA was performed with the within-subject factors stimulus orientation (45º, 90º, 135º), compatibility (compatible vs. incompatible manual rotation) and the between-subjects factor age. Only a main effect of compatibility, $F(1, 64) = 6.28$, $p < .05$, $\eta^2 = .09$, and the interaction between compatibility and age, $F(3, 64) = 3.25$, $p < .05$, $\eta^2 = .13$, were significant. In the condition with compatible manual rotation, participants produced fewer errors than in the incompatible condition, and this difference decreased with increasing age.

Discussion

Significant effects of age, stimulus orientation, and the interaction of these two factors are consistent with results from previous studies, and indicate that all age groups did mentally rotate the stimuli, and that rotation speed increased with age.

Separate analyses for age groups yielded a significant effect of compatibility for the younger children (5-year-olds and 8-year-olds) but not for older children (11-year-olds) and adults. Younger children showed slower response times for incompatible compared to compatible trials. These results are in line with recent findings (Funk et al., in press) that incompatible hand positions during mental rotation of hands had an even larger effect on children than on adults. This suggests that the ability to decouple visual mental activities and motor processes develops with age.

The absence of a compatibility effect for the adults is inconsistent with the results reported by Wexler et al. (1998). It is possible that a difference in attention demands or speed of manual rotation could account for these conflicting results. Wexler et al. (1998) trained their participants to maintain a particular speed they memorized prior to the study. In this study, we ensured for each trial that the participants were in fact performing the manual task, but it would have been too hard for the young children if they also had to more strictly control the speed of their movement. For adults on the other hand, the present task was quite easy and their response times were very fast. A faster manual rotation speed might have been necessary to interfere with their faster mental rotation. Thus, age differences in mental rotation speed might account for the age differences in the magnitude of the compatibility effect. If this were the case, we would expect a large decrease in compatibility effect between 11-year-olds and adults. However, the largest difference in the magnitude of the compatibility effect was found between 8- and 11-year-olds.

An increase in work load by adding a manual rotation task to the mental rotation task led to an increase in response times, even more so for children. However, general processing capacities cannot explain the selective difference between incompatible and compatible manual and mental rotation that distinguishes between younger and older children or adults. As a further sign of selective interference, and in line with Wexler et al. (1998), compatibility of manual and mental rotation resulted in a shift in the typical V-shaped response time function, favoring the direction of manual rotation.

Further behavioral experimentation, supported by neuroimaging studies, might give a deeper insight in the conditions under which motor activities interfere with children's mental activities, and whether there is in fact a developmental shift allowing for better decoupling visual and motor processes with increasing age.

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References

Black, T., & Schwartz, D. L. (1996, June). *When imagined actions speak louder than words*. Paper presented at the annual meeting of the Jean Piaget Society, Philadelphia.

Childs, M. K., & Polich, J. M. (1979). Developmental differences in mental rotation. *Journal of Experimental Child Psychology, 27*, 339-351.

Cooper, L. A., & Shepard, R. N. (1973). The time required to prepare for a rotated stimulus. *Memory and Cognition. 1, 246 250*.

Cooper, L. A., & Shepard, R. N. (1975). Mental transformation in the identification of left and right hands. *Journal of Experimental Psychology: Human Perception and Performance, 1*, 48-56.

Corballis, M. C., & McLaren, R. (1982). Interaction between perceived and imagined rotation. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 215-224.

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

Funk, M. Brugger, P. & Wilkening, F. (in press) Motor processes in children's imagery: The case of mental rotation of hands. *Developmental Science.*

Jolicoeur, P., & Cavanagh, P. (1992). Mental rotation, physical rotation, and surface media. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 371-384.

Kail, R., Pellegrino, J., & Carter, P. (1980). Developmental changes in mental rotation. *Journal of Experimental Child Psychology*, *29*, 102-116.

Kosslyn, S. M. (1994). *Image and brain*. Cambridge, MA: MIT Press.

Kosslyn, S. M., Margolis, J. A., Barrett, A. M., Goldknopf, E. J., & Daly, P. F. (1990). Age differences in imagery ability. *Child Development, 61*, 995-1010.

Kosslyn, S. M., Thompson, W. L., Kim, I. J., & Alpert, N. M. (1995). Topographical representations of mental images in primary visual cortex. *Nature, 378*, 496-498.

Marmor, G. S. (1975). Development of kinetic images: When does the child first represent movement in mental images? *Cognitive Psychology, 7*, 548-559.

Marmor, G. S. (1977). Mental rotation and number conservation: Are they related? *Developmental Psychology, 13*, 320-325.

Parsons, L. M. (1987). Imagined spatial transformations of one's hands and feet. *Cognitive Psychology, 19*, 178-241.

Parsons, L. M. (1994). Temporal and kinematic properties of motor behavior reflected in mentally simulated action. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 709-730.

Parsons, L. M., Fox, P. T., Downs, J. H., Glass, T., Hirsch, T. B., Martin, C. C., Jerabek, P. A., & Lancaster, J. L. (1995). Use of implicit motor imagery for visual shape discrimination as revealed by PET. *Nature*, *375*, 54-58.

Piaget, J., & Inhelder, B. (1971). *Mental imagery in the child*. New York: Basic.

Rieser, J. J., Garing, A. E., & Young, M. F. (1994). Imagery, action, and young children's spatial orientation: It's not being there that counts, it's what one has in mind. *Child Development, 65*, 1262-1278.

Sekiyama, K. (1982). Kinesthetic aspects of mental representations in the identification of left and right hands. *Perception and Psychophysics*, *32*, 89-95.

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

Wexler, M., Kosslyn, S. M., & Berthoz, A. (1998). Motor Processes in Mental Rotation. *Cognition, 68,* 77-94.

Wohlschläger, A., & Wohlschläger, A. (1998). Mental and manual rotation. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 397-412.