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When estimating reachability in space, young children and the elderly are similar

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Abstract: This study examined the age-related ability to mentally represent action in the context of reach estimation via use of motor imagery in children, young adults, and a group of older adults. Participants were instructed to estimate whether randomly presented targets in peripersonal (within actual reach) and extrapersonal (beyond reach) space were within or out of reach of their dominant limb while seated. In regard to total accuracy, results indicated that children and older adults were similar, but scores were significantly lower than those of young adults. Whereas all groups displayed greater error in extrapersonal space, once again children and older adults were similar, but significantly different than young adults. That is, children and older adults displayed greater overestimation responses. Although other factors are discussed, the literature provides a hint that differences are due in part to distinctions in brain structure and functioning.
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Key Words: Mental representation, motor imagery, action processing.

Introduction

Motor programming theory suggests that an integral component in an effective outcome is an adequate *action representation* of the intended actions. This representation is viewed as a component of an internal forward model, which is a neural system that simulates the dynamic behavior of the body in relation to the environment (e.g., Wolpert, 1997; Wolpert & Kawato, 1998). This theory proposes that internal models make predictions (estimates) about the mapping of the self to parameters of the external world; processes that enhance planning and execution of action. These representations are hypothesized to be an integral part of action planning (Caeyenberghs, Tsoupas, Wilson, & Smits-Engelsman, 2009; Choudhury, Charman, Bird, & Blakemore, 2007a, 2007b; Molina, Tijus, & Jouen, 2008; Skoura, Papaxanthis, Vinter, & Pozzo, 2005; Wolpert, 1997). Skoura, Vinter, and Papaxanthis (2009) suggest that improvement in action representation during childhood maybe due in large part to refinement of internal models.

Complementing the forward model idea and central to our interests is the suggestion that motor imagery is involved in the prediction of the consequences of one's actions (e.g., Bourgeois & Coello, 2009; Kunz, Creem-Regehr, & Thompson, 2009; Lorey et al., 2010). Furthermore, it has been suggested that *motor imagery provides a window into the process of action representation* (Jeannerod, 1997, 2001; Munzert, Lorey, & Zentgraf, 2009).

Although several studies have recently emerged concerning the ability to mentally represent action via use of motor imagery, none to our knowledge have reported a lifespan comparison of a wide age range of participants. Here, we examined a form of action representation – estimation of reachability. That is, using motor imagery to judge (estimate) whether an object is within or out of reach. As a form of motor imagery, the estimation of reach paradigm has drawn the interest of contemporary researchers for examining the processes involved in action representation with adults (Coello et al., 2008; Coello & Delevoye-Turrell, 2007; Gabbard, Cacola, & Cordova, 2011; Gabbard, Cordova, & Lee, 2009a; Lamm, Fischer, & Decety, 2007) and children (Gabbard, Cordova, & Ammar, 2007; Gabbard, Cordova, & Lee, 2009b). Determining whether an object is reachable or not is primarily a function of the observer's perceived body capabilities. That idea complements the internal modeling notion of "can I do this?" and, "what are the consequences?" which arguably, are relevant questions in planning movements. More specific to reach, one of the initial steps in programming such movements is to derive a perceptual *estimate* of the object's distance and location relative to the body.

This means that an individual must be able to perceive critical reach distances beyond which a particular reach action is no longer afforded and to which a transition to another reach mode must occur. For example, is the object close enough to reach while seated, or do I need to stand?

Studies of children and young children

In 2007, we examined reach estimation via use of motor imagery in children 5- to 11 years of age and young adults (Gabbard et al., 2007). Whereas there was no difference between groups for total error, a significant distinction emerged in reference to peripersonal [area within reach] and extrapersonal [area beyond reach] space. For children, significantly more error was exhibited with extrapersonal compared to peripersonal targets; there was no difference in adults. The groups did not differ in peripersonal space; however, adults were substantially more accurate in extrapersonal space. In addition, children revealed a greater overestimation bias. We wish to note that previous reports indicate that children and young adults tend to overestimate (e.g., Coello & Iwanow, 2006; Fischer, 2000; Gabbard, Ammar, & Rodrigues, 2005; Robinovitch, 1998). In essence, those data revealed a problem with mentally representing action (associated with body-scaling) in extrapersonal space for children.

Studies of older adults

To our knowledge, the only study reporting reach estimation with older adults came from our lab (Gabbard, Cacola, & Cordova, 2011). That investigation compared young adults (mean age: 20) and 23 older adults (mean age: 77) and found that the younger group was significantly more accurate than the older adults. Whereas both groups made more errors in extrapersonal space, the values were significantly higher for the older group; that is, they overestimated to a greater extent. The findings of that paper added to the general notion that there is a decline in the ability to mentally represent action with advanced age (> 64 years) (Mulder, Hochstenbach, Heuvelena, & Otter, 2008; Personnier, Kubicki, Laroche, & Papaxanthis, 2010; Saimpont, Mourey, Manckoundia, Pfitzenmeyer, & Pozzo, 2010; Skoura, Personnier, Vinter, Pozzo, & Papaxanthis. 2008). Tasks used with those studies primary involved comparisons of imagined and executed movements (aka chronometry paradigm) of the hand, arm, and whole body. In addition, Mulder and colleagues (2008) found that older adults were worse than their younger counterparts regarding vividness of movement imagery via questionnaire, especially from a first person perspective.

Therefore, the purpose of this study was to examine the influence of age (children, young adults, and older adults) on the ability to mentally represent action in the context of estimation of reach. Based on previous work, it seemed reasonable to expect that young adults would outperform both children and older adults.

Method

Participants

The sample consisted of 41 children ages: 7- (*n* = 13), 9- (*n* = 15), and 11 years (*n* = 13), young adults (*n* = 30), and older adults (23). The mean ages for each group were 6.73 ± 0.4 years old, 8.47± 0.5 years old, 10.92± 1.1 years old, 20.07 ± 1.46 years old, and 77.13± 8.59 years old, respectively. All participants were right-handed as determined by results of the Lateral Preference Inventory (Coren, 1993). Participants were screened using a questionnaire to ensure that none had a history of past or present sensorimotor impairment and had normal or optically corrected-to-normal vision. Our Institutional Review Board (IRB) for the ethical treatment of human subjects approved the experimental protocol and consent form. Participants were informed of the experimental procedures and voluntarily signed a consent form before participating in this study (children provided verbal consent after parents signed the consent form).

Measures

Actual maximum reach (used as the comparison) and imaged reach responses were collected via *short-throw* projection *system (Sanyo Model PLC-XL50) linked to a computer* programmed with Visual Basic. Visual images were systematically projected onto a table surface at midline (90^o). The table was constructed on a sliding bracket frame, allowing it be moved back and forward for adjustment to the participant. Participants sat in an adjustable ergonomics chair fixed, aligned with the midline of the table and projected image midline. Seatpan height (surface is metal and nondepressive) was set to 105% of participant's popliteal height. Popliteal height was the distance from the underside of the foot to the underside of the thigh at the knees. Table height was then adjusted to the midpoint between seatpan height and seated eye height. Table and seatpan positioning were modified from Carello, Grosofsky, Reichel, Soloan, and Turvey (1989) and Choi and Mark (2004). To aid in establishing actual reach limitations for a 1-*df* action (described in the next section), a commercial seatbelt system was modified and secured to the back of the chair. The room was darkened with the exception of light from the computer monitor and visual images projected onto a black colored tabletop; reach targets consisted of white 2 cm diameter circles. The fixation point was projected onto a rectangular box (with a 45 degree angle surface) placed at midline approximately 45 cm from the most distal target. Figure 1 presents an illustration of the general experiment setup.

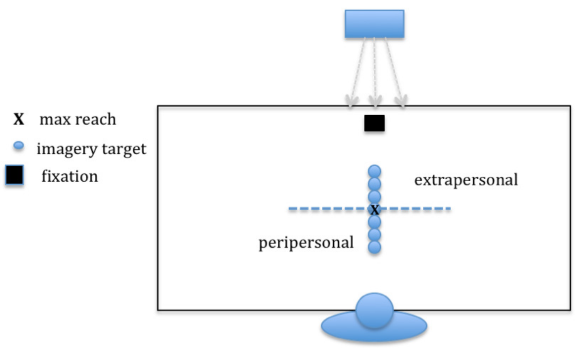

Figure 1: . Illustration of the general experimental setup.

Procedure

To begin, participants were systematically positioned in the chair and introduced to the task for determining 'actual' maximum reach - full extension of the right limb and middle finger to slide forward a penny using a 1-df reach (Carello et al., 1989). A 1-df reach involved a comfortable effort of the hand, forearm, and upper arm acting as a single functional skeletal unit. Based on maximum reach, seven imagery targets (2 cm diameter) were randomly programmed with '4' representing actual reach complemented with three target sites farther and three sites closer touching at the rims (Figure 1). In essence, actual reach was 'scaled' to individual arm lengths, therefore allowing acceptable comparison. Participants were asked to focus while kinesthetically 'feeling' themselves (first-person perspective) executing the movement with the right limb – therefore being more sensitive to the biomechanical constraints of the (motor imagery) task (Johnson, Corballis, & Gazzaniga, 2001; Sirigu & Duhamel, 2001; Stevens, 2005). The dominant (right) hand was placed within a drawn box on the table close to the torso at midline, while the nondominant limb rested on the participant's upper left thigh under the table. Participants were asked to make judgments relative to whether the target was within ('yes') or out of reach ('no'). Each participant was trained and provided practice in use of motor imagery. For imaged trials, data collection began with a 5 s "Ready!" signal –immediately followed by a central fixation point lasting 3 s, at the end of which was a tone. The image appeared immediately thereafter and lasted 500ms with another tone at the end – which required an immediate (after imaging) verbal response. Target presentation was given in random order with 5 trials at each of the seven targets.

Data analysis

For estimation of reach, total score, overall accuracy across targets, was defined as the number of correct responses out of the total number of trials. A correct verbal estimation of reach was when the participant responded "yes" when actually the target was within reach, or "no" when in fact, the target was out of reach. These data were analyzed using a 1-way *ANOVA* for the five age groups. To determine the distribution of error across targets (where did the errors occur?), the number and differences between wrong and right answers for each target, in each condition, were calculated using frequency data analyses and chi-square procedures. The reader should keep in mind that there were seven target presentations with "4" representing the participant's actual maximum reach. Incorrect responses at the three targets above (distal to) the actual (5 – 7) indicated an "overestimation", whereas an incorrect response at any of the lower (proximal) targets (1 – 4) was considered an "underestimation." For example, if a participant noted that target 5 was reachable ('yes') when in fact it was not, it was an overestimation. As noted earlier, targets 1-4 were identified as peripersonal (within reach) space, whereas targets 5-7 defined extrapersonal (beyond reach) space.

Results

Initial ANOVA results indicated that the three children age groups were not significantly different ($p > .05$). Therefore, with the remaining analyses, data for the three youngest groups were combined and compared to young and older adults. Analysis of variance results for total accuracy indicated that the groups were different; $F(2, 92) = 7.79$, $p < .01$, $\eta^2 = .145$. *Tukey* post-hoc analysis revealed that young adults were more accurate than children and older adults; children and older adults were not different. Mean scores for children, young adults and older adults were 26.79 ± 4.11, 29.93 ± 2.70, and 26.61 ± 3.96, respectively.

In regard to the distribution and general direction of error, whereas all groups made more errors in extrapersonal space (targets 5-7), values were significantly higher for children and older adults; that is, they overestimated to a greater extent. Figure 2 shows responses comparing age groups with the distribution of error across targets. In comparison with young adults, children displayed significantly more errors on targets 6 (39% versus 13%) and 7 (25% versus 1%); $p < .001$. Similarly, compared to young adults, older adults displayed more errors on targets 5 (56% versus 39%), 6 (44% versus 13%) and 7 (20% versus 1%); all $p < .001$. In regard to the comparison of children and older adults, analyses indicated no significant differences, $p > .05$.

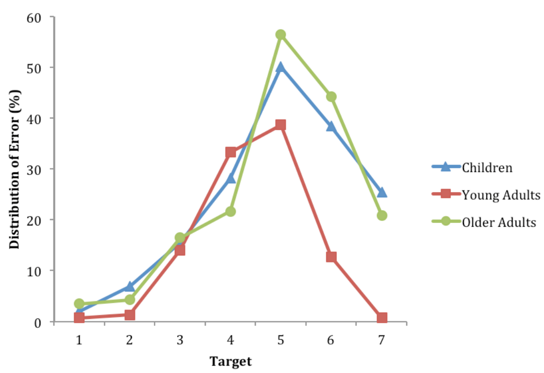

Figure 2: Distribution of error across targets for groups.

Discussion

We tested children (ages 7-11 years), young adults, and older adults on the ability to estimate reachability via use of motor imagery. Underscoring this idea was the suggestion that motor imagery provides a window into the process of action representation (Jeannerod, 1997, 2001; Munzert et al., 2009). In addition to the action representation question, estimation of reach also provides insight to motor planning in the form of body-scaling reach actions.

The following key results were found. First, in regard to total accuracy, children and older adults were similar, but scores were significantly lower than those of young adults. And second, whereas all groups displayed most error in extrapersonal space, indicating the overestimation behavior, once again children and older adults were similar, but significantly different than young adults. That is, children and older adults displayed greater overestimation responses.

In regard to the comparison of children and young adults, these findings complement those reported by Gabbard et al. (2007). More specific, as shown here, there were significant differences between peri- and extrapersonal space. For adults, error values for responses in peripersonal and extrapersonal space were similar. On the other hand, children exhibited considerably more error in extrapersonal compared to peripersonal space. Between group results indicated no differences in peripersonal space; however, children were significantly less accurate in extrapersonal space and revealed greater overestimation. We also wish to note that in the Gabbard et al. 2007 study, using a larger sample of 71 children representing three age groups, like the results reported here, no differences were found between age groups.

Why the differences between children and young adults? A few considerations warrant suggestion. First, in regard to total accuracy, it seems reasonable to assume that part of the outcome may be a reflection of experience in reaching workspace. However, one could also bring in the fact that the 7-year-olds were not different from the older children (11- year-olds). The greater difference in extrapersonal space suggests that perceptual (e.g., visual perception, spatial awareness) and psychological factors (level of confidence), as well as experience may be involved. With our task, participants were asked to derive an estimate of the object's distance relative to the body and via motor imagery map the coordinates for a body-scaling response. With our 2007 report (Gabbard et al.), we hypothesized that the body-scaling difference in extrapersonal space maybe due to developmental differences in use of visual information via egocentric and allocentric representations. Studies with adults demonstrate that actions of this nature (reaching) are most effective when using an egocentric frame of reference as opposed to depending on allocentric information alone (Bradshaw, Watt, Elliot, & Riddell, 2004; Goodale & Humphrey, 1998; Stevens, 2005). Current reports of children are somewhat conflicting – for example, one notes that children rely on both visual pathways during perceptual and visuomotor activities; therefore suggesting that these pathways 'are not' functionally segregated (Hanisch, Konczak, & Dohle, 2001). On the other hand, another study concluded that the systems are relatively mature and segregated by 7 years of age (Rival, Olivier, Ceyte, & Bard, 2004).

More recently, discussions of this topic have included developmental differences in regard to brain structure changes. Work with typically developing children and adults suggests that there is a close link between development of the parietal cortex, action representation, and the ability to formulate internal models associated with motor imagery; suggesting that both are refined through the adolescent years (e.g., Blakemore & Sirigu, 2003; Choudhury et al., 2007a; Koscik et al., 2009; Skoura et al., 2009). Another aspect associated with the cognitive aspects of action representation is development of the prefrontal cortex (e.g., Skoura et al., 2009). Molina et al. (2008) suggest that motor imagery in children can be interpreted in terms of a general development of cognitive processes involved in motor representation principally determined by internal changes in the prefrontal and parietal structures of the brain. From the body of work, one could conclude that age-related differences between children and young adults found in the present study may be attribution to maturity of brain structures associated with the ability to use motor imagery.

Arguably, the unique contribution of the study is the inclusion and comparison of older adults to younger groups. Overall, our results indicated that the older group was similar to children, with both being significantly different than younger adults. In essence, much like other neuropsychological factors, we see a developmental trend of increasing, peak and ultimate decline in ability. It would seem that we could rule out the experience factor and perhaps the notion of confidence. Regarding the latter, confidence, why would older adults be overconfident by overestimating? That is, stating yes that they can reach the target, when in fact they could not? It stands to reason that such behavior would be observed in children, but not in the elderly. We would be speculated that older adults would have shown less confidence by underestimating.

So, why would older adults, like children, be less accurate and display greater overestimation than younger adults? One consideration is likely differences in brain structures associated with use of motor imagery. With children, the literature shows that areas such as the parietal and prefrontal cortex were not mature. Research with older adults, although quite limited, also indicates that decline in motor imagery may reflect functional changes in the aging brain; for example, the parietal cortex (Personnier, Bally, & Papaxanthis, 2010). Therefore, a case, although small, can also be made that with advanced age there is a decline in cognitive processing associated with the ability to create internal models and mentally represent action. Obviously, factors other than the ability to mentally represent action could have contributed to lower accuracy rates in the older adults. For example, although we screened for 'normal or corrected vision (at least 20 / 30), the dim light in the experimental room could have affected the elderly more than the younger adults; however the problem was not mentioned during training and familiarization trials. Another factor could be depth perception – research indicates that the elderly have more difficulty determining how close, or far away an object is (Bian & Andersen, 2008).

For the elderly, one could also assert that the decline in the ability to accurately estimate (and plan motor actions) has implications for the quality of daily living. Perhaps most prominent, in regard to prospective (predicting) actions, are considerations of movement efficiency and injury; with falls being a prominent consideration with the elderly. In the context of estimation of distance reachability, it is not unreasonable to suggest that by misjudging the distance of an object intended to reach, the individual could lose postural control and fall (e.g., Can I reach and grasp that object without losing my balance and fall?).

In conclusion, our findings indicate that children (7- 11 years) and older adults are similar and significantly different than younger adults. That is, young adults are more accurate, especially in extrapersonal space. The literature hints and our speculation is that one of the factors underlying the difference are due to distinctions in brain structure and functioning – namely, immature development (in children) and decline in the elderly in specific brain structures associated with mental representation.

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