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Research Article

A Lifespan View on Modulation of Peripersonal and Extrapersonal Reach Space via Tool Use

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AT A GLANCE
Tool use (temporary extension of the limb) can modulate the borders between peri- and extrapersonal space. A lifespan trajectory explored in this study suggests that development and decline of action representation with tool use follow distinct paths, with children being less accurate than young and older adults. In general, it also appears that retraction of space with a tool seems to be more difficult than extension of space, regardless of the length of the tool.

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AIM: This study examined lifespan characteristics associated with tool use in the modulation of peripersonal and extrapersonal space.
METHOD: Three age groups: Children (7-12 years), Young Adults (19-23 years), and Older Adults (65-92 years) were presented with two experiments using an estimation of reach paradigm involving arm and tool conditions and a switch-block of the opposite condition.
RESULTS: Experiment 1 tested Arm and Tool (20 cm length) estimation and switch-block conditions (from Arm to Tool and Tool to Arm) and found a significant effect for Age and Condition (*ps* < .05). Post-hoc analysis for Age indicated that children were significantly less accurate than young and older adults. Analysis for condition revealed significant differences for the Arm Switch-Block condition (Retraction) when compared to Tool and Arm estimations. Experiment 2 was similar to Experiment 1 with the exception of using a 40 cm length tool. Results were analogous to those found in Experiment 1.
CONCLUSION: Considered together, these results hint that: (1) the ability to be as accurate when estimating reach with a tool and arm is present across the lifespan, (2) development and decline of action representation follow distinct paths, and (3) retraction of space seems to be more difficult than extension.

KEYWORDS: tool use | lifespan | space perception | space recognition | estimation of reach

INTRODUCTION

Motor representations involve the ability to formulate (accurately) internal models and to code space with and without reach[1]. This coding of space as near and far is not only determined by the arm-reaching distance, but also depends on how the brain represents the extension of the body space. One of the lines of research associated with the general topic of space is tool use. Although the length of our effectors (arms and legs) limits our action space, we can use different tools (*e.g.*, sport implements: real and virtual [Wii]) to extend our physical body structure and consequently, our action space. Evidence indicates that tool use (temporary extension of the limb) can modulate the borders between peri- and extrapersonal space[2-6].

Even though the notion that tool use extends the neural representation of multisensory space immediately surrounding the hands is pervasive in the literature (see Holmes[7] for a review), little is known about the lifespan course associated with tool use and the perception and modulation of peripersonal space and extrapersonal space. Children and older adults are commonly compared to young adults and frequently perform worse in that comparison, but it is unclear how opposite developmental stages of the lifespan compare to each other. A recent developmental study[1] comparing children and adults' tool use in the context of reach estimation has indicated that children as young as 6 years of age are capable of being as accurate when estimating reach with a tool as they are with their arm. In action representation/ estimation of reach abilities (without tools), it has been suggested that the ability to represent actions is similarly less accurate in children and older adults when compared to young adults[8].

With aging, the use of tools becomes more crucial for successful completion of daily-living activities. Older adults commonly use tools for postural control and locomotion (*e.g.*, canes and walkers), and understanding how tools are incorporated into action representations is important for a better understanding of how the aging brain processes modulation of space. For example, Caçola, Martinez, & Ray[9] found that older adults had difficulty with retraction of space from a tool to their arm, regardless of the length of the tool. In addition, the results indicated a negative relationship for accuracy with a longer tool (40 cm) and age.

Therefore, this study aimed to provide a lifespan perspective on the modulation of peripersonal and extrapersonal space via tool use. To this end, two experiments with two tool lengths (Experiment 1: 20 cm; Experiment 2: 40 cm) using a reach estimation task with and without tools were conducted with a group of children, young adults, and older adults. The assumption was that children would be similar to older adults when representing actions with a tool, and both groups would be less accurate than young adults. I also examined whether lifespan modulation of spaces could be influenced by tool length. To confirm the extension of space caused by tool use[2-6], I did not expect to find differences in arm and tool accuracy within any group.

EXPERIMENT 1

METHODS

Participants

Experiment 1 involved 77 participants representing three lifespan stages: Children, 7 -12 years (*n* = 33), Young Adults, 19-23 years (*n* = 19), and Older Adults, 65-92 (n = 25). The mean ages were 9.15, 21.53, and 74.92 years, respectively. All participants were screened using a questionnaire (filled out by the parent for children) to ensure normal vision and that none had a history of past or present sensorimotor impairment. For the purposes of this study, only participants identified as strong right-handers via manual performance rather than questionnaire were selected. That is, those for whom all items scored in that lateral direction using the Lateral Preference Inventory[10] were included in the investigation. The experimental protocol and consent form were approved by the Institutional Review Board (IRB) for the ethical treatment of human subjects. 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.

Apparatus

The apparatus and procedures described here are equivalent to the ones used by Caçola and Gabbard[1] and Caçola, Martinez, and Ray[9]. Fig. 1 depicts the experimental setup. Actual maximum reach (used as the comparison) and simulated reach responses were collected via an overhead projection system linked to a PC programmed with *Visual Basic*. Visual images were systematically projected onto a table surface at midline (90°). 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 to the floor, aligned with the midline of the table and projected image midline. Seatpan height (surface was metal and nondepressive) was set to 105% of participant's popliteal height. Popliteal height is 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 et al.[11]. To aid in establishing actual reach limitations for a one degree of freedom (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 white visual images projected onto the table programmed with a gray background surface. 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.

Two conditions were conducted: one in which the participants used their arm only (ARM) for reach and the other in which participants used a TOOL. For both conditions, participants wore a modified commercial racquet glove that was sized to fit comfortably their right arm; the size range available was XS to XL. The glove was modified as follows. A finger-nail size piece of green luminescent tape was attached to the tip of the middle finger (point of reach determination)

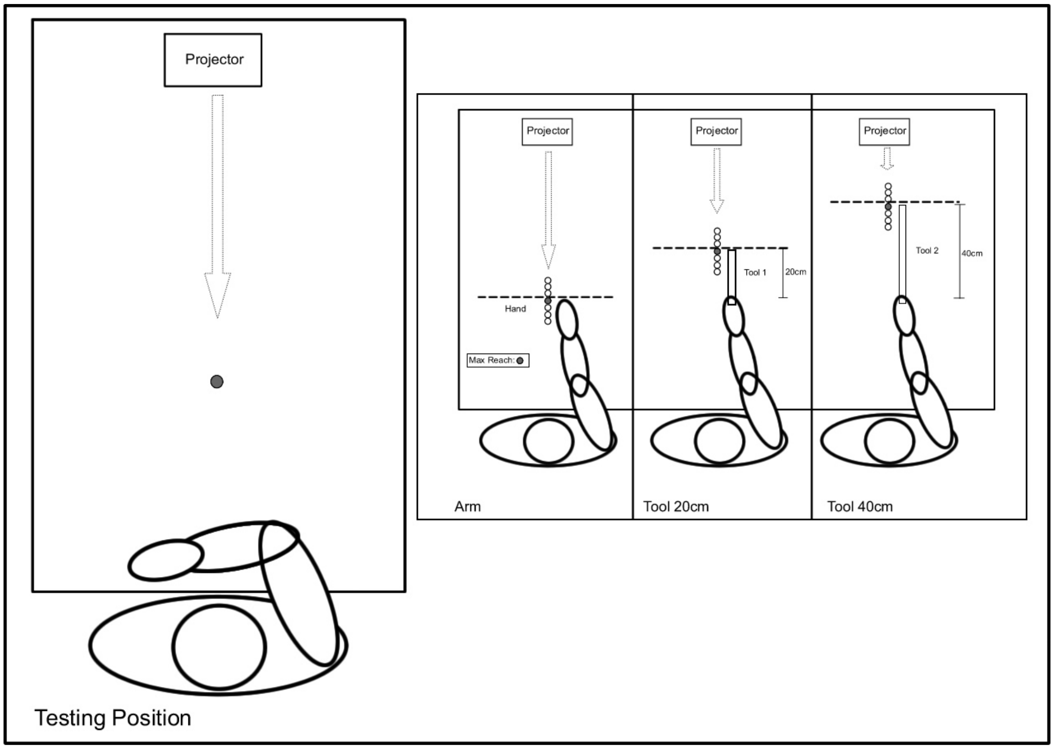

Figure 1. General experimental set-up and representation of the 20 cm and 40 cm tools.

In addition, a retractable antenna-type pointer was attached to the under side of the glove with the tip of the pointer leveled with the tip of the middle finger of the glove. The tip of the pointer also had a piece of luminescent tape attached; both conditions were conducted in very dim lighting. For the TOOL condition, the pointer was extended 20 cm out from the tip of the middle finger site, whereas for ARM trials, the pointer was retracted (or placed) at actual middle finger tip. Each participant's maximum reach was individually scaled with the arm and tool (as described in the Procedure). These measurements provided the base-line comparison for estimates of reach in space.

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 pull back a penny using a 1-*df* reach[11]. A 1-*df* reach involved a comfortable effort of the arm forearm, and upper arm acting as a single functional skeletal unit. Based on maximum reach, seven targets (2 cm diameter-penny size) were randomly programmed with the middle target (4) representing the actual reach of the participant complemented with three sites farther (targets 5, 6, and 7) and three sites closer (targets 1, 2, and 3). Targets 1-4 represented peripersonal space (within reach), while 5-7 were outside of reach (extrapersonal space). In essence, actual reach was 'scaled' to individual arm lengths, therefore allowing acceptable comparison. For the TOOL condition program, 20 cm was added to the ARM maximum reach value. As a reliability check (primarily for violation of 1-*df* constraint), the 20cm added value on the program was compared to actual maximum reach with the TOOL using the first few participants; values were equivalent.

For the trials using ARM and TOOL, participants were asked to kinesthetically 'feel' themselves executing the movement ("feel your arm extending…"); therefore being more sensitive to the biomechanical constraints of the task[12,13]. For the ARM condition, the right (focus) arm was placed within a drawn box on the table close to the torso at midline and the non-dominant limb rested on the participant's upper left thigh under the table. Use of the TOOL was similar with the exception that the tool was placed (rested) at a 45° angle parallel to the front edge of the table – right place within the box. In this condition, participants were instructed to focus on the illuminated tip of the pointer in order to make the judgments of reachability.

Data collection began with a verbal "Ready!" signal – that was immediately followed by a central fixation point lasting 3 s, at the end of which the participant heard a tone. The image appeared immediately thereafter and lasted 500 ms. A second tone then provided the signal for the participant to respond immediately with a "Yes" or "No" in reference to whether the stimulus was 'reachable' or not. A second experimenter served to verbally reinforce instructions regarding imagery technique and refocusing to the central fixation point with each trial. No feedback on performance was given.

ARM and TOOL conditions were presented in counterbalanced order. Target presentation was given in random order. The ARM condition consisted of 21 trials (3 trials for each one of the 7 targets) and a 'switch- block' of 7 trials with the TOOL. The switch-block consisted in estimating reach immediately with the opposite condition of the initial 21 trials. When participants started with the ARM, the pointer was pulled to 20 cm and participants were told they would now estimate with the tool. When participants started with the TOOL, the pointer was retracted to the back of the glove and participants were told to then estimate reach with their ARM. Therefore each condition had 21 trials followed by a switch-block of 7 trials of the opposite condition. Between conditions, participants had a larger break; they were instructed to get up and move around lab for a few minutes. The intent of the switch-block was to gain insight to the adjustment period associated with extending and retracting space. Individual testing required approximately 45 minutes and was completed within a single session; all testing was conducted in an isolated room.

Before starting the task, participants were able to perform exploratory actions (no more than two) to see where they could reach with their arm and with the tool. Then, each participant was trained in the use of motor imagery, with and without the tool, and allowed two practice trials with each condition. In a few cases, one additional trial was allowed.

Treatment of the Data

Total score, representing overall accuracy across targets, was defined as the percentage of correct responses out of the total number of trials for each block (ARM, TOOL, SB-ARM, SB-TOOL). A correct verbal estimation of reach was when the participant responded 'yes' when actually the target was within reach, or 'no' when the target was out of reach. As a reminder, targets 1 – 4 were defined as peripersonal (within reach) space, and targets 5-7 as extrapersonal (out of reach) space. These data were analyzed using a 4 (Condition) x 3 (Age group) repeated measures analysis of variance (ANOVA) procedure. As appropriate, post hoc analyses using Tukey's tests were performed ($p < .05$). For simplicity of presentation, results are presented of a proportion (% accurate) of total score.

RESULTS

ANOVA results indicated that Condition and Age groups were significantly different, $F(3,222) = 4.00$, $p < .01$, $\eta^2 = .05$ and $F(2,74) = 17.02$, $p < .01$, $\eta^2 = .31$. The interaction was not significant, $F(6,222) = 2.06$, $p > .05$, $\eta^2 = .05$. Post-hoc analysis for Condition revealed significant differences between SB-ARM (76.62±21.47) and ARM (84.78±10.01) and between SB-ARM and TOOL (82.12±12.83). The value for SB-TOOL was 93.23±8.73. For Age groups, Children (74.71±16.75) were significantly less accurate than both Young Adults (87.97±12.95) and Older Adults (85.47±19.79). Both adult groups were not different than each other.

EXPERIMENT 2

METHODS

Participants

Experiment 2 involved 74 participants representing three lifespan stages: Children, 7 -12 years (n = 30), Young Adults, 19-23 years (n = 19), and Older Adults, 65-92 (n = 25). The mean ages were 8.77, 20.58, and 74.92 years, respectively. Screening procedures were the same as Experiment 1.

Apparatus

The apparatus for this experiment was identical to the apparatus in Experiment 1 with the exception of the length of the tool (40 cm instead of 20 cm).

Procedure

See details regarding the procedures in Experiment 1. Experiment 2 followed the same procedures as Experiment 1.

Treatment of Data

As with the data analysis of Experiment 1, descriptive statistics and analysis of variance (ANOVA) procedures were employed. All the variables were determined the same way as in the previous experiment.

RESULTS

ANOVA results indicated that Condition and Age groups were significantly different, $F(3,213) = 3.51$, $p < .05$, $\eta^2 = .04$ and $F(2,71) = 21.57$, $p < .01$, $\eta^2 = .37$, respectively. The interaction was not significant, $F(6,213) = 1.55$, $p > .05$, $\eta^2 = .04$. Post-hoc analysis for Conditions revealed significant differences between SB-ARM (74.32±22.05) and ARM (83.33±13.24) and between SB-ARM and TOOL (80.56±16.99). For Age groups, Children (74.76±18.89) were significantly less accurate than both Young Adults (88.72±14.67) and Older Adults (89.52±14.41). Both adult groups were not different than each other.

DISCUSSION

The primary goal of this study was to gain insight into the lifespan course of spatial representation and modulation in reference to tool use. While Experiment 1 examined tool use in children, young adults, and older adults with a 20 cm tool, Experiment 2 investigated whether a tool of 40 cm influenced the lifespan ability to modulate peripersonal and extrapersonal space. Overall, both experiments showed similar results: Children were less accurate than Young and Older Adults, and differences in Conditions pertained to significantly lower values when participants retracted space (SB-Arm Condition) when compared to Tool and Arm accuracy.

The first observation reflects the general lack of significant differences between arm and tool (20 cm and 40 cm) conditions, which supports the notion that tool use results in an expansion of the body schema and peripersonal space[14]. When incorporating a tool into the body schema, participants tend to be as accurate when estimating reach with the tool as they are with their arm. These results were expected, since it is known that relatively brief experience using novel tools is sufficient to influence the internal representation of the dynamics of the tool-limb system[15].

On the other hand, a unique observation emerged with regards to the switch-block conditions. Participants were significantly less accurate when retracting space, or their accuracy decreased when there was a sudden switch from Tool to the Arm condition. Accuracy in the switch block of the arm was also lower compared to accuracy in the main Arm condition. Initially, we expected that incorporating a tool (rapidly) into the body schema would be more challenging, that is, participants would take longer to adjust to their regular levels of accuracy when adding an extension to their body schema. The very opposite happened, participants were significantly less accurate when retracting space from the tool to the arm. The most likely explanation for this result is experience, based on the notion that perceived increases of body size are more frequent and robust than perceived decreases[16]. In this experimental design, it is also possible that participants, when using the tools, relied on the use of allocentric cues (target and surrounding information) for their estimations, instead of mapping distance to and from the body by establishing egocentric (distances from self) coordinates[17,18]. In that way, when participants had to estimate reach with their arm after dropping the tool, they had to shift their point of reference, which may have caused lower accuracy of responses.

Secondly, we expected to find accuracy differences between children and young adults[1], as it seems reasonable to assume that young adults have accumulated different experiences in reaching workspace[9]. 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. Molina et al.[19] suggest that action representation 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.

Surprisingly, there were no differences between young and older adults. We expected that older adults would be significantly less accurate than young adults, performing similarly to children[8]. There are indications that, in the elderly, there is a likelihood of weakness in internal models of action[20-22]. In this sample, it is possible that older adults were able to maintain “younger” levels of accuracy due to their motor experience. All older adult participants were regular attendees (3x a week) of a university program that included Pilates and Wii exercise, and most tended to engage in other types of activities outside of the program. As Hillman and colleagues[23] pointed out, in a review of studies concerning physical activity, exercise training, and the brain, fitness may serve as a neuroprotective function for aging.

This study certainly has limitations, as in the size of the different groups as well as the use of a few age ranges to represent a broader aspect of the lifespan. However, this study also yields three major contributions to the understanding of the lifespan course of tool use. First, I have established developmental profiles using the same task for a broad range of ages. Overall, children performed less accurately than adults, and surprisingly, older adults performed similarly to young adults, suggesting that development and decline of action representation follow distinct paths. Second, I provide a plausible support to the extension of space via tool use when using action representation abilities. In addition, because the conditions did not interact with age groups, it is clear that, at least in an action representation type of task, the tool system is intact very early in life, and the ability to be as accurate when estimating reach with a tool and arm is present across the lifespan. Third, while tool length does not seem to influence expansion and retraction of space (since both experiments revealed similar results), it is possible to conclude that retraction seems to be more difficult than extension of space with a tool.

In regard to the extension of this work, future studies should consider the issue of spatial extension with different tool lengths and types of implements. Effective modulation of space is used in a wide variety of daily living, working, and recreational activities. Furthermore, effective modulation is important for physical safety in activities such as reaching for objects. For example, without effective modulation and reach estimate, one could lose postural control and perhaps fall; a common problem with the elderly. And more specifically, in the context of tool use, coupled with our findings, it is possible that older adults need more time when retracting space in order to adjust to their "arm" parameter representations[9], in order to avoid a possible fall. In addition, the understanding of how special populations mentally represent action in space planning has the potential to improve the quality and diversity of rehabilitation protocols, as well to create new assessment / diagnostic techniques.

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