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VISUOMOTOR CONTROL IN CONTINUOUS RESPONSE TIME TASKS ACROSS DIFFERENT AGE GROUPS[1]

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Summary.—The goal was to examine whether visuomotor control and choice response time shared age-related developmental trajectories, and if prior computer experience played an important role in control processes. Children (6–7, 8–9, 10–11 yr.), younger adults (24 yr.) and older adults (76 yr.) performed the cursor pointing and choice response time (CRT) tasks with a computer mouse. Participants moved the mouse cursor back and forth to click two targets on the screen as fast and accurately as possible. In the CRT, based on visual stimuli, participants moved and clicked one of the three targets on the screen as fast and accurately as possible; the time between stimulus onset and clicking the correct target was recorded as the choice response time. Visuomotor performance increased with age to younger adulthood but was worse in the older adult group. CRT performance was also positively related to age among the groups of children, with scores leveling off in the young adult group. Computer experience was statistically significantly related only to visuomotor control, but not to CRT. Optimal CRT performance required only sub-optimal visuomotor control. Cognitive and sensory age declines may be related to the poorer CRT performance in the oldest age group.

Humans undergo drastic developmental changes in cognitive and motor capacities, reflecting the maturation of the neural and sensory systems throughout the lifespan. In childhood, remarkable gains in cognitive and motor control occur, and can be explained by the maturation of the central nervous system and the increased speed of information processing (Diamond, 2000; Yan, Thomas, Stelmach, & Thomas, 2000; Lambert & Bard, 2005). Motor and cognitive developments are positively associated,

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supporting the idea of the interdependence of motor and cognitive development (Smirni & Zappala, 1989; Diamond, 2000; Rhemtulla & Tucker-Drob, 2011).

Age and experience play important roles in motor execution and learning. For example, children do not perform adult-like reaching movements and prehension until 6 and 8 yr. of age, respectively (Kuhtz-Buschbeck, Boczek-Funcke, Illert, Joehnk, & Stolze, 1999; Favilla, 2006). Unlike reaching and prehension tasks, development of fine motor movement can be even more protracted. Young children (e.g., 4 yr. of age) cannot usually make continuous manual actions smoothly. However, their performance increases markedly in early childhood and they achieve smoother continuous movements by 6 yr. of age (van Mier, 2006). The increasing fine motor proficiency is usually accompanied by improvements of sensorimotor components (Case-Smith, 1995). A significant decrease of movement time (MT) is observed in 6-, 8-, and 10-yr.-olds in a two-dimensional pointing task (Lambert & Bard, 2005). Handwriting speed, which relies heavily on fine motor control, increases in students from Grades 1 to 5 (Karlsdottir & Stefansson, 2002; Feder & Majnemer, 2007). Beyond ~~the~~ 10 yr. of age, fine motor movements are still developing. Proficiency of repetitive finger movements reaches a plateau at approximately 15 yr. (Largo, Catflisch, Hug, Muggli, Molnar, Molinari, *et al.*, 2007). Fine motor control is not fully developed until adolescence (Diamond, 2000). Thereafter, from young to older adulthood, motor performance gradually deteriorates (Krampe, 2002; Leversen, Haga, & Sigmundsson, 2012). Older adults have longer MT and poorer spatial coordination in fine motor control than young adults (Contreras-Vidal, Teulings, & Stelmach, 1998; Smith, Sharit, & Czaja, 1999).

Computers play an indispensable part in our daily lives. Exposure to computers potentially enhances cognitive, visual, and fine motor abilities (Straker, Pollock, & Maslen, 2009). Although using a computer mouse imposes high cognitive and motor demands on its user, it is the most commonly used input device other than the keyboard (Atkinson, Woods, Haslam, & Buckle, 2004; Wood, Willoughby, Rushing, Bechtel, & Gilbert, 2005). The effect of using a computer mouse has been widely investigated over several decades. Similar to other research into fine movements that rely on visuomotor capabilities, a general finding is that cursor-pointing performance (speed and accuracy) improves significantly during childhood. More specifically, pointing performance improves from the age of 5 to 12 yr. (Joiner, Messer, Light, & Littleton, 1998; Lane & Ziviani, 2010). Donker and Reitsma (2007) showed that aiming and clicking responses with a computer mouse are faster in 7-yr.-olds than 6-yr.-olds. However, the 6- and 7-yr.-olds performed at a similar level to adults who are not familiar with using a computer mouse in a pointing and clicking task (Crook, 1992). This indicates that the visuomotor capabilities required for controlling a computer mouse mature early in childhood.

Lane and Ziviani (2010) suggest that the plateau performance of cursor pointing is attained when a child reaches the age of 9 or 10 yr. Other studies, however, have shown that plateau performance is not reached until young adulthood (Donker & Reitsma, 2007), which is supported by the findings that young adults generally have superior proficiency in cursor pointing compared to other age groups, and that they are more accurate and faster than older children 12 to 14 yr. of age and older adults (Hertzum & Hornbaaek, 2010). These developmental issues should be examined in a single study to eliminate the differences in experimental paradigms across studies.

The discrepancy of the results is probably caused by the confounding of computer experience, as implicated in Crook's study (1992). Previous studies have found that the proficiency of using a computer mouse can be improved through training, even over a short period of time. After training for five days, 3-yr.-olds can demonstrate substantial improvements both in pointing time and accuracy (Revelle & Strommen, 1990). Interestingly, adults with more computer experience outperform those with less experience. The training effect is evident even among older adults (Crook, 1992; Smith, Umberger, Manning, Slevin, Wekstein, Schmitt, *et al*., 1999). These results show that computer use can improve cursor-pointing performance, but whether such an experience can enhance visuomotor performance, which in turn improves the more cognitively demanding cursor pointing and clicking tasks, remains an open question.

The goal was to investigate whether visuomotor capability and choice response time (CRT) performance share similar developmental trajectories.

Hypothesis 1. Because the CRT task depends heavily on visuomotor ability, simple cursor-pointing and the CRT performances should have similar developmental trajectories.

Hypothesis 2. Computer experience can improve participants' visuomotor ability, so participants with prior computer experience should have higher performances in both simple cursor-pointing and the CRT tasks.

Method

Participants

Three groups of children were recruited for this study. To examine the effects of aging, older adults were also included. In the study, 18 younger children, 20 middle children, 20 older children, 12 young adults, and 24 older adults were recruited. Based on the self-report, all participants had normal or corrected-to-normal vision, and had no known cognitive or neurological disorders. Informed consent was received either from the participants or their parents before the commencement of the experiments (Table 1).

TABLE 1
DEMOGRAPHICS OF PARTICIPANTS

Group	M/F	*M* Age	*SD* Age	Age Range	Computer Experience (Yes/No)
Young Children	10/8	6.8	0.40	6.2–7.5	10/8
Middle Children	10/10	8.7	0.44	8.0–9.5	8/12
Older Children	11/9	10.7	0.53	10.0–11.6	13/7
Young Adults	5/7	23.8	2.08	21.0–28.0	6/6
Older Adults	8/16	76.2	3.86	67.0–82.0	13/11

Procedure

Participants reported (yes or no) whether they had any prior computer experience (i.e., intentional, physical control of any computer input device) before the experiments, which served as a dummy-coded independent variable. Following this, they were asked to work on a simple cursor-pointing task with a stand-alone personal computer. In a trial of the task, 2 'ME' icons (1.5 × 2 cm) were present on the screen, one on the left and another on the right. The 'ME' icons were the targets to click in the task. Participants had to move a mouse cursor back and forth on the computer screen to click the 'ME' icons (1.5 × 2 cm) alternately as fast and accurately as they could for 30 sec. The distance between the 'ME' icons was 13 cm. One practice trial was allowed for familiarization and was then followed by 15 experimental trials. The number of successful pointing movements to the 'ME' icons was recorded.

Upon completion of the simple cursor-pointing task, participants were instructed to work on the CRT task. In this task, three shapes were placed horizontally (from left to right: square (2 × 2 cm), rectangle (2 × 2.8 cm), and circle (2 × 2 cm)) on the screen; the closest distance between shapes was 3.5 cm. Participants had to click the button (0.6 × 2.5 cm) as fast as possible under the shape with the flashing light on the computer screen. The location of the flashing light was random. Each trial consisted of 20 flashing lights. Each participant finished 20 trials of this task. Response accuracy and the response time for each pointing movement were recorded.

According to Fitts' law [$MT = a + b \log_2 (2A/W)$, where a and b are constants, A is target distance, and W is target width], the speed of aiming movements can be affected by target distance and size (Fitts, 1954; Fitts & Peterson, 1964). Target size and distance were kept constant across participants and trials in the same task. In addition, participants were asked to work on the experimental tasks using their dominant hand.

Data Analysis

Response time data from unsuccessful pointing movements were discarded from analysis. The mean number of successful pointing movements per second (i.e., frequency) of the simple cursor-pointing task and the mean response time and the accuracy of the CRT task were computed. Two-way analyses of variance (ANOVA) on mean cursor-pointing frequency, mean response time, and accuracy were performed, with age group and computer experience as between-subjects factors. *Post hoc* comparisons were carried out with the Bonferroni procedure. Despite unequal sample sizes in different groups, ANOVA should still be robust given that none of the assumptions of ANOVA (independence of samples, normality, homogeneity of variance) were violated. Additional correlational analyses between age, mean cursor-pointing frequency, and mean response time of the CRT task were also conducted.

Results

Cursor-pointing Frequency

Figure 1 shows an overall pattern of the cursor pointing frequency of different age groups. There was a statistically significant age group ×

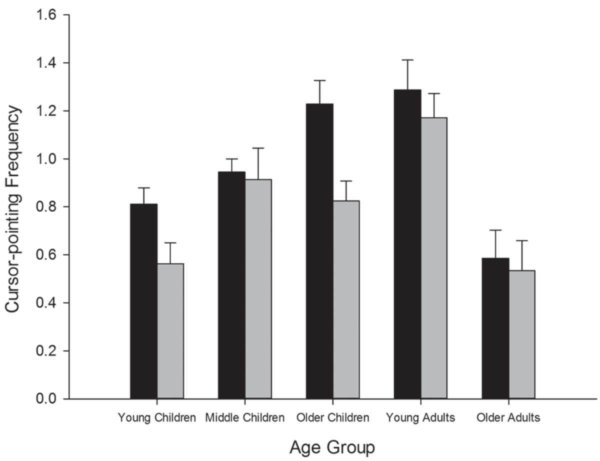

FIG. 1. Frequency of cursor pointing of groups of different ages and computer experience (• experience, • no experience). Error bars represent 95% *CI*.

computer experience interaction on pointing frequency ($F_{4, 84}=3.80$, $p<.01$, $\eta^2=0.15$). Participants with prior computer experience outperformed those without experience in the young and older groups of children ($p<.005$), but not in the other age groups (Fig. 1).

The main effect of age was significant ($F_{4, 84}=40.69$, $p<.001$, $\eta^2=0.66$). *Post hoc* comparisons showed that young children made fewer successful pointing movements than those in other age groups ($p<.001$) except the older adults ($p=.12$). Pointing speed was the greatest in young adults, who were significantly faster than the other groups (in comparison with young and middle children and older adults, $p<.001$; in comparison with older children, $p<.05$). In addition, there was a significant main effect of computer experience ($F_{1, 84}=20.67$, $p<.001$, $\eta^2=0.20$). Participants with prior computer experience generally pointed faster than those without experience.

Choice Response Time and Accuracy

A statistically significant main effect of age group on the CRT was observed ($F_{4, 84}=20.63$, $p<.001$, $\eta^2=0.50$). The main effect of computer experience was not significant ($F_{1, 84}=1.06$, $p=.31$, $\eta^2=0.01$), nor was the interaction between these independent variables ($F_{4, 84}=0.15$, $p=.96$, $\eta^2=0.01$). *Post hoc* comparisons showed that older adults were the slowest responders (in comparison with all the other age groups, $p<.001$). A significantly slower response speed was observed in young children than in middle children ($p<.05$). Middle and older children demonstrated a similar response speed to that of young adults ($p>.05$) (Fig. 2).

No significant main effects or interactions between independent variables were observed in choice response accuracy (main effect of age group, $F_{4, 84}=1.96$, $p=.11$, $\eta^2=0.09$; main effect of computer experience, $F_{1, 84}=0.10$, $p=.76$, $\eta^2=0.00$; age group × computer experience interaction, $F_{4, 84}=0.89$, $p=.47$, $\eta^2=0.04$; Fig. 2).

Correlational Results

Detailed correlational results were presented in Table 2. Age was correlated significantly with the choice response time and cursor-pointing frequency. A significant association between the choice response time and cursor-pointing frequency was also observed. The choice response time and visuomotor performance were negatively related.

Discussion

Visuomotor control and CRT performance were investigated in different age groups to assess whether they had similar developmental trajectories. Prior computer experience could influence performance in these two tasks. Results showed that both visuomotor control and the CRT improved substantially during childhood. Peak performance of the CRT was attained before peak visuomotor capability. The decline of CRT performance was

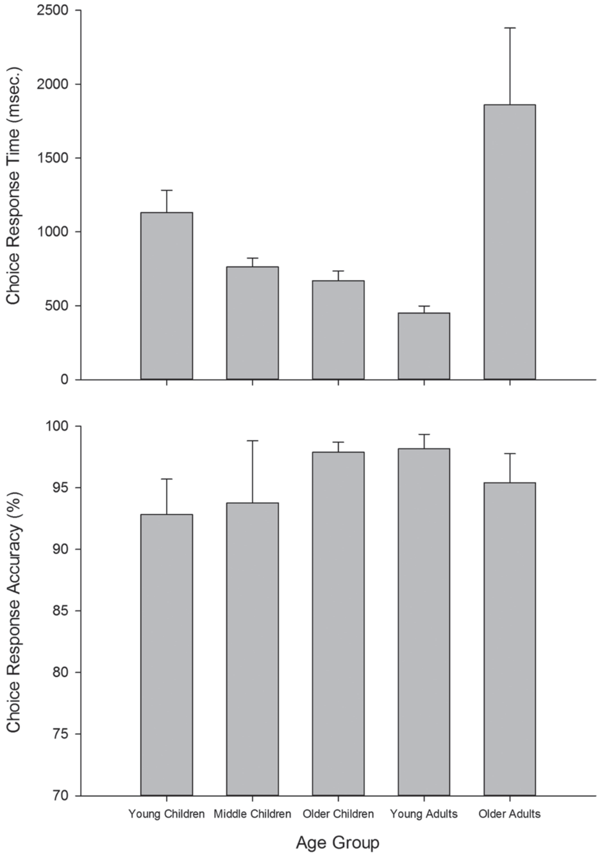

FIG. 2. Choice response time and accuracy of different age groups. Error bars represent 95% *CI*.

TABLE 2
CORRELATIONAL RESULTS

Comparison	*r*	95%*CI*
Age vs choice response time	.60	.43, .76
Age vs cursor-pointing frequency	−.49	−.67, −.31
Choice response time vs cursor-pointing frequency	−.70	−.84, −.54

Note.—The *p* values of all correlations were $< .001$.

faster than that of visuomotor capability when a person approaches older adulthood. Computer experience was found to moderate cursor-pointing performance but not CRT in certain age groups. Furthermore, correlational analyses show that age was positively related to visuomotor and CRT performances, respectively. Importantly, a strong negative association between the cursor-pointing frequency and CRT was observed.

The cursor-pointing task allowed the assessment of the participants' visuomotor control capability. Those with better visuomotor control should have a higher pointing rate. Visuomotor control improved from young childhood to young adulthood; performance deteriorated in the older adult group. The difference in visuomotor control between age groups may be related to the differences in the threshold of action initiation (Salthouse, 1996; Smith, *et al.*, 1999; Garvey, Ziemann, Bartko, Denckla, Barker, Wassermann, 2003; Falkenstein, Yordanova, & Kolev, 2006). Remarkable developments of the brain occur at an early age, in which somatosensory cortices mature earlier than the higher-order association cortices and prefrontal cortex (Gogtay, Giedd, Lusk, Hayashi, Greenstein, Vaituzis, *et al.*, 2004; Casey, Tottenham, Liston, & Durston, 2005). Along with the maturation of somatosensory regions, children are gradually able to attain high performance in visuomotor tasks. Optimal visuomotor performance is achieved when motor regions mature in adolescence (Paus, Zijdenbos, Worsley, Collins, Blumenthal, Giedd, *et al.*, 1999). During aging, the speed of information transmission and processing is reduced and motor behaviors will probably also slow down. Furthermore, when the threshold of action initiation is changed, the time required for accumulating sufficient neural activation to initiate a movement varies. This is supported by the findings that muscle activation is generally higher in older adults than their younger counterparts (Sandfeld & Jensen, 2005). These findings are largely consistent with previous results that visuomotor control continues to develop beyond childhood (Donker & Reitsma, 2007; Hertzum & Hornbaaek, 2010); it reaches its peak level at an age between young and older adulthood. As older adults have a higher threshold to initiate a movement (Falkenstein, *et al.*, 2006), they need more time to accumulate enough neural activation, resulting in slower responses.

In general, those with prior computer experience performed better in the cursor-pointing task. *Post hoc* comparisons show that the benefit associated with computer experience was significant only in young and older children. This is not consistent with previous results showing that computer experience is not related to children's motor development (Li & Atkins, 2004). The discrepancy may be a result of different experimental paradigms that impose varying demands on participants in assessing visuomotor control. Hitherto, no satisfactory explanation has been offered to account for the moderating effect of computer experience on the visuomotor development of some age groups but not others. Further study on this issue is warranted.

The developmental trend of the CRT is similar to that of cursor-pointing. The CRT and cursor pointing show dramatic improvements from childhood to young adulthood and deterioration thereafter. However, two distinct differences between the trends are noted. First, from middle childhood to young adulthood cursor-pointing performance increases, whereas the CRT showed no significant improvement. Second, young children and older adults show similar performance in the cursor-pointing task, whereas older adults performed worse than young children in the CRT task. Because there is no accuracy difference between the two age groups, it is unlikely that the response speed results are caused by a shift of strategy or a speed–accuracy trade-off. Instead, these developmental distinctions may be caused by the relatively low visuomotor requirements of the CRT task and the effects of cognitive and sensory decline during old age (Lord & Ward, 1994; Marsiske, Klumb, & Baltes, 1997).

The CRT task is very similar to the cursor-pointing task. Where they differ is the additional cognitive demands the CRT task imposes on participants. In the cursor-pointing task, a participant needs to point to and click two targets in fixed locations, alternately. However, there are three targets in the CRT task, and the target to point to and click is not predetermined. Therefore, compared to the cursor-pointing task, the CRT task requires participants to be attentive (especially spatial attention) for a certain period and to move the input device to a designated location to achieve a good performance. During childhood, there is a marked development of the anterior cingulate, a neural area subserving attentional capabilities, from 3 to 7 years of age (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). Besides attention, visuospatial abilities undergo substantial development during the early school years (Del Giudice, Grossi, Angelini, Crisanti, Latte, Fragassi, *et al*., 2000). The increased cognitive abilities and visuomotor control contribute to the rapidly improving performance in the CRT task from young to middle childhood. The middle child and young adult groups had similar CRT performance, so cognitive and visuomotor abilities in middle childhood are already sufficient for achieving the highest choice-response performance. Despite the continuous development of visuomotor control after middle childhood, such an additional improvement apparently does not improve CRT performance.

Cognitive and motor decline is evident (Ren, Wu, Chan, & Yan, 2013) ~~in older adults~~. In addition to being more cautious, older adults generally have greater motor and perceptual noises and slower neural processing, compared to their younger counterparts (Walker, Philbin, & Spruell, 1996; Walker, Philbin, & Fisk, 1997). The current findings show that visuomotor control in the older adult group declined to the level of the young children. The older adult groups' CRT performance was lower than that of the younger children, suggesting that cognitive decline reduces CRT performance in addition to decreasing visuomotor control. Such an interpretation is consistent with Alkjær, Pilegaard, Bakke, and Jensen (2005), who suggested that the elderly find mentally demanding computer tasks more challenging than young people. Compared to the cursor-pointing task, the CRT task places additional cognitive demands on spatial attention and response selection as the participant has to move an input device to a certain spatial location based on the imperative stimulus (McLaughlin, Simon, & Gillan, 2010). Hence, the additional CRT performance reduction in the older adult group possibly can be attributed to substantial decline in spatial attention and response selection. This issue was not tested in the present study, but older adults may have poorer spatial attention and response-selection capabilities than young children; this could be examined in future research. This is consistent with Light's proposal that impaired attention and response selection contribute to poorer motor performance in the elderly (1990). In addition, it is in accordance with previous results suggesting that prefrontal functions commonly associated with aging may be responsible for the deficit in attention in aged people (Chao & Knight, 1997). Some may argue that older adults process stimulus information more poorly. But this interpretation is not likely, as both younger and older adults demonstrated comparable stimulus processing efficiency in an ERP study (Falkenstein, *et al.*, 2006). Rather, a reduction of sensory acuity commonly observed in older adults may play a part, besides substantial cognitive decline, in the deterioration of the CRT performance (Lord & Ward, 1994; Marsiske, *et al.*, 1997).

One surprising finding from this study is that computer experience was related to visuomotor control, but not to tasks with a greater cognitive demand. Individuals who have more computer experience use a mouse more often than others, thereby resulting in higher proficiency in its use. Furthermore, as computer anxiety can affect a person's performance, people with more computer experience often have greater confidence, and thus the adversarial effects caused by computer anxiety can be minimized (Laguna & Babcock, 2000).

Caution is required when interpreting the developmental trends of performance in the two tasks. First, these trends are not generally applicable to all motor tasks. Second, the trends do not show the exact age at which performance peaks and then starts to decline. One implication from the data is that there is a serious deterioration of performance between younger and older adulthood. In this study, participants were asked only if they had computer experience. Details about the frequency of computer use and the age when participants started to use a computer may be valuable in providing additional insight into the moderating role of computer experience in visuomotor development. Future research should consider obtaining more information about participants' computer-use habits; this would allow a more meaningful interpretation of the results (Li & Atkins, 2004).

The current results suggest that both children and older adults have poorer visuomotor performance in general. Walker, *et al*. (1996) suggest that increasing the gain on the mouse may benefit older users, which is likely to be equally applicable to children for improving their mouse using performance. However, more research into this issue is warranted. Compared to children, older adults are poorer mouse users when cognitive demand is high. Thus, designing software interfaces and input devices to reduce cognitive load is especially important for older users.

In conclusion, CRT performance is determined by an array of abilities, such as visuomotor control, spatial attention, and response selection. The CRT task is not a very demanding one. A distinct reduction in the CRT performance indicates more than deterioration of visuomotor control; cognitive and sensory aging may also be responsible. Computer experience can moderate simple visuomotor development but not the performance of tasks involving greater cognitive demands.

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