Aging and Tennis Playing in a Coincidence-Timing Task With an Accelerating Object: The Role of Visuomotor Delay

Régis Lobjois, Nicolas Benguigui, and Jean Bertsch

The purpose of the present study was to determine whether playing a specific ball sport, such as tennis, could maintain the coincidence-timing (CT) performance of older adults at a similar level to that of younger ones. To address this question, tennis players and nonplayers of three different age ranges (ages 20–30, 60–70, and 70–80 years) performed a simple CT task consisting of timing their response (pressing a button) to coincide with the arrival of a stimulus at a target. The stimulus moved at either an accelerating, constant, or decelerating velocity. As expected, all participants were affected by the velocity manipulation, which led to late and early responses to accelerating and decelerating stimuli, respectively. Whereas this response bias was increasingly pronounced with advancing age in nonplayers, no difference was found among player groups of different ages. Finally, we showed that the length of the visuomotor delay could explain the effect of nonconstant velocities.

Key words: age, perceptuomotor processes, response timing

Older adults generally have more difficulty than younger ones adapting their actions to the displacement of a moving object in real-world tasks, such as grasping (e.g., Bennett & Castiello, 1995) or crossing a street (e.g., Oxley, Fildes, Ihsen, Charlton, & Day, 1997). One can assume that part of the age-related differences in these tasks comes from less efficient coincidence-timing (CT) processes (e.g., Stelmach & Nahom, 1992). To be successful in CT actions, such as catching or hitting balls, the individual must determine when a moving object will reach a target point in space and tune his or her action to the object’s motion based on temporal information (e.g., Tresilian, 1995). In simple CT tasks, which consist of timing an impulse type of response (pressing a button) to coincide with the moving object’s arrival at the target, women and men over the age of 60 years generally perform with greater overall error and variability than do younger ones. Furthermore, older adults usually produce late responses (Haywood, 1980; Meeuwsen, Goode, & Goggin, 1997). Although this result has been explained mainly by age-related declines in perceptual processes (e.g., Haywood, 1980), the effects of age on perceptuomotor processes should not be overlooked.

To better understand the perceptuomotor problems of older adults, we need to examine the mechanisms involved in CT tasks. Perfect accuracy in such tasks requires issuing the motor-response command before the moving object arrives at the target (Benguigui, Ripoll, & Broderick, 2003). To plan this action, the individual has to take into account his or her own visuomotor delay (VMD; i.e., the perceptuomotor-process inertia time between the visual registering of information and the effecting of the action; e.g., Carlton & Carlton, 1987; Tresilian, 1993). As VMD is known to increase with motor-task complexity (Carlton, 1992; Zelaznik, Hawkins, & Kisselburgh, 1987) and be longer in older adults (Bennett & Castiello, 1995; Warabi, Noda, & Kato, 1986), one can assume that the older adult lateness observed by Haywood (1980) and
Meeuwsen et al. (1997) comes from difficulty integrating an increasing VMD into the response at execution time. In contrast to these negative effects of aging, there is evidence that older adults remain able to perform well under certain circumstances, such as when they exercise or do physical activities (like running, swimming, or cycling). Some studies have shown that physically active older adults are more accurate and consistent in CT tasks than less active ones (Christensen et al., 2003; Del Rey, 1982). However, the negative effects of aging in active older adults are still observable, because their performance remains lower than that of younger adults (Haywood, 1980). If age deficiencies in CT tasks are moderated only by physical activities, one can assume that aging effects could be eliminated by a specific activity, such as a ball sport, in which CT actions are common.

One way to investigate this question would be to test older adults, who play or do not play a ball sport, using a CT task with accelerating velocities. It has been shown that velocity variations make CT tasks more difficult and require accurate tuning (e.g., Benguigui et al., 2003; Ripoll & Latiri, 1997). The difficulty comes from the observer’s inability to use acceleration information from the moving object to estimate the time-to-contact (TTC), that is, the time remaining before the object reaches the observer or a particular point in space (Kaiser & Hecht, 1995; Lee, Young, Reddish, Lough, & Clayton, 1983). Instead, first order information, such as the optical variable tau, may be used to estimate a first order TTC (TTC1). But TTC1 does not account for acceleration (see the gap between TTC1 and real TTC in Figure 1) and, therefore, does not define the real temporal relationship between the observer and the object. In CT actions that depend on the inertia time of the perceptuomotor system (i.e., VMD), TTC1 information is picked up at some time before the moving object arrives at the target (which corresponds to the individual’s VMD). Due to the discrepancy between TTC1 and real TTC before stimulus arrival, CT errors will be large (Benguigui & Ripoll, 1998). Furthermore, the longer the VMD, the greater the errors will be. This can be explained by the fact that information is picked up at points where the difference between TTC1 and real TTC is increasing (see Figure 1). This means that all individuals should be affected by nonconstant velocities. Sedentary older adults, who have longer VMDs, should make more errors with accelerating and decelerating motion, because they have to initiate their responses sooner than younger adults. However, older adults who play a ball sport on a regular basis may be able to minimize such errors, because they maintain a short VMD. These hypotheses were addressed in two experiments in which we examined (a) the effects of nonconstant velocities on CT accuracy as a function of age and tennis playing, and (b) the link between VMD length (measured in a stop-signal task) and errors at nonconstant velocities in a CT task.

### Method

#### Participants

Three age groups (ages 20–30, 60–70, and 70–80 years) with two different levels of tennis experience (players and nonplayers) participated in two experiments (see Table 1 for the mean age and standard deviation of each group). All groups contained eight male participants. As is typically the case in research on aging (e.g., Fleury & Bard, 1985; Haywood, 1980; Meeuwsen et al., 1997), we selected only men to avoid a possible gender effect and minimize the heterogeneity of the groups. The younger groups were composed of students and the older groups of retired individuals living on their own. By comparing two different older adult age groups (ages 60–70 and 70–80 years), our aim was to extend previous results in which only one older group was tested (e.g., Fleury & Bard, 1985; Haywood, 1980; Meeuwsen et al., 1997) to gain insight into CT performance changes in the course of aging.

![Figure 1](image-url) Illustration of the gap between real time-to-contact (TTC) and TTC1 determined from first order information (estimated TTC) in the accelerating (+4.3 m/s²) and decelerating (-4.3 m/s²) conditions, as a function of real TTC (these conditions were used in Experiment 1). A participant with a visuomotor delay of 250 ms and assumed to use TTC1 ought to initiate his response for a TTC1 value equal to 250 ms. Given that real TTC was 228 ms when TTC1 was 250 ms in the accelerating velocity condition, an error of 22 ms could be predicted. In contrast, a participant with a VMD of 180 ms ought to respond late with an error of 12 ms.
Tennis was chosen as the ball sport for two main reasons. First, ball velocity is rarely constant in tennis due to variable muscular actions, spins, air resistance, or ball impact. Perceptuomotor processes, particularly VMD, are, therefore, needed on every ball hit to update the relationship between the ball’s ever changing trajectory and the player’s motor response. Second, tennis is probably the most common ball sport played across the life span, which made it possible to recruit experienced older players with a long playing history.

To be eligible for the study, the “players” were required to have played tennis between 2 and 4 hours a week for at least 10 years (see Table 1). With this much practice, one can assume that the players have repeated the concerned perceptuomotor processes thousands of times. All the players were active in tennis clubs, with a significant history of regular playing, but neither the younger nor the older players were of professional caliber. Our aim was to recruit tennis players who played on a regular basis and had experience but were not “experts” in the game. In other words, our goal was more to study the effects of “social” playing, like that done by most older tennis players, than expert playing. The nonplayers had no previous or current experience in tennis or other ball games.

All participants were right-handed and reported normal or corrected-to-normal vision. None reported any neurological disorders or ocular pathologies, such as glaucoma, cataract, or macular degeneration. All signed an informed consent form before taking part in the study.

**Experiment 1: CT Performance at Nonconstant Velocities**

**Design and Task**

The experimental display was composed of a runway of red light emitting diodes (LEDs) that simulated the displacement of a moving object from left to right, ending at a target. The apparent continuous motion was generated on a 4-m simulator by the sequential switching on of 200 LEDs placed at 2-cm intervals.

Participants sat 4 m away from the apparatus, facing the target. Once informed of the appearance point of the stimulus, they started each trial by pressing a button with their preferred hand. To respond, they were required to press the button a second time to make their response coincide with the arrival of the moving object at the end of the runway. The time between the participant’s response and the illumination of the last LED was the measure of response accuracy (in ms).

Participants performed the task in each of three velocity conditions: a constant-acceleration velocity (+4.3 m/s², from 2.95 to 5.88 m/s), a constant velocity (4.38 m/s), and a constant-deceleration velocity (-4.3 m/s², from 5.81 to 2.88 m/s). The viewing time of the moving stimulus was identical (680 ms) in all conditions. Note that the final velocities in the three conditions were different. To ensure that the expected effect of nonconstant velocities was due to the velocity variation (and not the final velocities), two “control” conditions with a constant velocity were added (5.88 and 2.88 m/s, with the same viewing time). The control conditions were used to compare constant to nonconstant velocities ending with the same arrival speed.

**Procedure**

Following an explanation by the experimenter, a training session was conducted consisting of 15 randomly presented trials with three different velocities (two nonconstant, +1.9 m/s² and -1.9 m/s², and one constant). During the training session, feedback about temporal accuracy (size and direction of error, in ms) was given to the participants after each trial. During the experimental session, each participant performed 8 trials per velocity condition (for a total of 24 trials²), and

<table>
<thead>
<tr>
<th>Age group</th>
<th>Age (years)</th>
<th>Years</th>
<th>Hours per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Players</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20–30</td>
<td>22.9</td>
<td>15.3</td>
<td>3.50 0.76</td>
</tr>
<tr>
<td>60–70</td>
<td>66.0</td>
<td>30.9</td>
<td>3.25 1.04</td>
</tr>
<tr>
<td>70–80</td>
<td>75.3</td>
<td>37.0</td>
<td>3.13 0.99</td>
</tr>
<tr>
<td>Nonplayers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20–30</td>
<td>25.9</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>60–70</td>
<td>64.7</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>70–80</td>
<td>74.0</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Note. M = mean; SD = standard deviation.
the velocity order was randomized. Corrective feedback (in ms) was given after each trial during data collection. The two control conditions were presented in one block of 16 trials at the end of the nonconstant-velocity session, using an identical experimental procedure.

For each participant and each condition, constant error (CE) and variable error (VE) were calculated. CE was the algebraic mean of the error, which was equal to the difference between the actual arrival time and the participant’s response. CE scores indicated the directional bias of the responses (early responses had a negative sign, late responses a positive sign). VE was equal to the standard deviation of the errors and indicated the response dispersion. An analysis of variance (ANOVA) was carried out on CE and VE, with age group (20-30, 60-70, and 70-80) and tennis playing (players and nonplayers) as between-participant factors and velocity condition (accelerating, constant, and decelerating) as a within-participant factor. Significance was set at .05. The effect size (η²) was also computed. Significant differences were detected using a Newman-Keuls post hoc test when necessary. A similar analysis compared nonconstant to constant velocities ending with the same arrival speed (i.e., +4.3 m/s² vs. 5.88 m/s and -4.3 m/s² vs. 2.88 m/s).

Results

As expected, the error analysis on CE revealed a main effect of velocity, $F(2, 84) = 538.32$, $\eta^2 = .88$. Responses were late when the stimulus was accelerating ($M = 25$ ms), early when it was decelerating ($M = -24$ ms), and slightly biased when its velocity was constant ($M = 3$ ms). The results also indicated significant two-factor interactions between age group and velocity, $F(4, 84) = 6.26$, $\eta^2 = .22$, and between tennis playing experience and velocity, $F(2, 84) = 90.57$, $\eta^2 = .42$. The three-factor interaction between age, playing experience, and velocity also reached significance, $F(4, 84) = 4.93$, $\eta^2 = .18$. This interaction is depicted in Figure 2. In players, the post hoc analysis yielded no age-related difference in any of the velocity conditions. However, in nonplayers, both older groups were significantly different from the younger one in the accelerating velocity condition but not in the decelerating condition. The absence of an age effect in the decelerating condition may be due to the fact that the younger group was more likely to produce earlier CT responses than the other groups, as shown by their systematic negative CE responses at all constant velocities ($M = -5$, -12, and -7 ms, for the constant velocity and the two control conditions, respectively). This tendency may have affected their performance in the decelerating velocity condition, thus cancelling the age-related effect. The means for each group (as well as standard deviations) are given in Table 2.

Two additional analyses were performed to make sure the velocity effect was due to the velocity variation and not the different final velocities in the nonconstant conditions. A first ANOVA ($Age_3 \times Tennis \ Playing_2 \times Velocity_2$) compared CE in the decelerating condition to CE in a constant velocity condition in which the velocity (2.88 m/s) was equal to the final velocity of the decelerating condition. This analysis revealed that for all age groups the response bias was not as great at the constant velocity as in the decelerating condition, $F(1, 42) = 130.52$, $\eta^2 = .75$ (see Table 2). The second ANOVA ($Age_3 \times Tennis \ Playing_2 \times Velocity_2$) confirmed a significant difference between CE in the accelerating condition and CE in the constant velocity condition in which the velocity (5.88 m/s) was equal to the final accelerating velocity, $F(1, 42) = 72.26$, $\eta^2 = .63$ (see Table 2). These results support the conclusion that the observed biases were, in fact, due to the velocity variation and not to the final velocities.

Last, an analysis of variance on VE revealed a main effect of age, $F(2, 42) = 12.51$, $\eta^2 = .37$. VE was higher for the 70–80-year-olds ($M = 31$ ms) than for the 60–70-year-olds ($M = 24$ ms) and the 20–30-year-olds ($M = 21$ ms), who did not differ from each other. There was no other main effect or interaction on VE.

Experiment 2: VMD and CT Errors in the Nonconstant Velocity Conditions

This experiment was designed to measure the VMD length of each participant, using a stop-signal task, and explore the link between VMD and CT accuracy in nonconstant velocity conditions.
Design and Task

The experimental display was the moving object simulator used in Experiment 1. The participants sat as above, 4 m away from the apparatus, facing the target. A stop-signal procedure (e.g., Logan, 1994) was used to measure VMD. Participants were asked to produce two kinds of responses, depending on the stimulus trajectory. Stimulus movement along the trajectory was either visible until the stimulus arrived at the target or occluded before it arrived. When the trajectory was visible up to the target, participants were required to press a button at the same time the stimulus arrived at the target, as in the previous experiment. Trials with occlusion were called catch trials. On catch trials, the participants were asked to inhibit their response (not respond). The occlusion time (duration) was varied across trials between 150 and 330 ms in steps of 20 ms (for a total of 10 occlusion times).

With this procedure, the probability of responding to a catch trial was a function of occlusion time and VMD length. In catch trials in which the occlusion occurred before the ”last” information used to produce the response was picked up, participants ought to be able to inhibit their responses. In these cases, VMD was shorter than TTC at occlusion time. In contrast, in trials in which the occlusion occurred after the pick up of the “last” information used to produce the response, participants should no longer be able to inhibit their responses. In these cases, VMD was longer than TTC at occlusion time. The overall probability of error (i.e., pressing the button when the stimulus trajectory was occluded) should, therefore, be higher for participants with a longer VMD.

For all trials, the apparent stimulus moved at a constant velocity (2 m/s), and the viewing time for each complete trajectory was 1 s. Note that only one velocity was used in this experiment, because VMD length is known to be independent of stimulus velocity (e.g., Benguigui et al., 2003).

Procedure

Participants were told that the ability to inhibit their response was as important as their ability to press the button accurately when the stimulus was not occluded. This explanation was given to ensure that they would not focus on one part of the task and neglect the other. The participants then performed one 20-trial practice block that included four catch trials. For the catch trials, the stimulus was occluded 300 ms before it reached the end of the runway. Corrective auditory feedback was provided for CT accuracy (in ms) and response inhibition on catch trials. During the testing session, the participants performed 150 CT trials and 5 catch trials per occlusion time (for a total of 50 catch trials). The trials were divided into five blocks of 40 trials, and catch trials occurred 25% of the time in each block (i.e., 10 times) equally often at each occlusion time (i.e., once per occlusion time per block). The location and presentation order of each occlusion time in a block were randomly distributed across groups, participants, and blocks. Corrective feedback was provided.

Data Analysis

Psychometric curves were obtained for each participant from the responses to catch trials, as a function of occlusion time (see Figure 3 for an illustration). The response probability ranged between 1 (participant always responding for occlusion times shorter than VMD) and 0 (participant never responding for occlusion times longer than VMD). Logistic functions were fit to the psychometric curves for each participant. The logistic function is a classical psychophysical function and a convenient model for psychometric curves describing human performance on sensory tasks (e.g., Treutwein & Strasburger, 1999). To determine each participant’s VMD, we used the mean of the logistic function, as typically done in

<table>
<thead>
<tr>
<th>Age group years</th>
<th>Decelerating condition (4.38 m/s)</th>
<th>Constant velocity (4.38 m/s)</th>
<th>Accelerating condition (4.38 m/s)</th>
<th>Control condition (2.88 m/s, 5.88 m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Players</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20–30</td>
<td>-19</td>
<td>10</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>60–70</td>
<td>-17</td>
<td>9</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>70–80</td>
<td>-21</td>
<td>9</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Nonplayers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20–30</td>
<td>-25</td>
<td>9</td>
<td>-5</td>
<td>10</td>
</tr>
<tr>
<td>60–70</td>
<td>-30</td>
<td>13</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>70–80</td>
<td>-34</td>
<td>11</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Mean</td>
<td>-24</td>
<td>12</td>
<td>2</td>
<td>12</td>
</tr>
</tbody>
</table>

Note. M = mean; SD = standard deviation.
Results

The analysis conducted on VMDs (Age, x Experience, ..) revealed that VMD increased significantly with age. \( F(2, 42) = 8.83, \eta^2 = .29 \). VMD was 196 (SD = 15 ms), 217 (SD = 23 ms), and 225 ms (SD = 25 ms) in the three age groups, respectively. This increase was significantly reduced by tennis playing, \( F(2, 42) = 9.08, \eta^2 = .17 \), because tennis players had shorter VMDs (\( M = 188, 207, \) and 214 ms, with SD = 8, 24, and 17 ms for the 20–30, 60–70, and 70–80-year-old players, respectively) than did nonplayers (\( M = 204, 225, \) and 236 ms, with SD = 16, 19, and 29 ms for the 20–30, 60–70, and 70–80-year-old nonplayers, respectively). However, the interaction between age group and tennis playing was not significant, \( F(2, 54) = 0.01, p = .98 \).

VMD-Based Error Prediction in the Nonconstant Velocity Conditions

Errors in the nonconstant velocity conditions of Experiment 1 were predicted on the basis of two assumptions: participants were assumed to (a) pick up information at a time corresponding to their VMD, and (b) use TTC1 instead of TTC. Errors were determined by calculating the difference between TTC1 and real TTC when TTC1 was equal to VMD (see Figure 1 for an illustration with the accelerating velocity). The predicted errors were then compared to the actual ones. Because of a possible bias of some participants on CT tasks (i.e., a general tendency to respond late or early), an overall error (OE) was calculated for the predicted and actual data. OE was equal to the difference between the CEs in the accelerating and decelerating conditions. These values are presented for each group in Table 3. To determine whether VMD could account for the CT bias, a regression analysis was performed with predicted OE as the independent variable and actual OE as the dependent variable. The regression analysis yielded a significant relationship between the predicted and actual results, \( r^2 = .37, F(1, 44) = 26.47, p < .0001^5 \) (see Figure 4). Note that this correlation was still significant when the age effect was partialled out. This finding confirms our hypothesis that VMD is a relevant factor in explaining CT responses.

Discussion

As hypothesized, accuracy in coincidence timing was clearly affected by the velocity variation. All participants responded too late in the accelerating velocity condition and too early in the decelerating velocity condition. The effect of nonconstant velocities was additionally supported by the fact that the accelerating conditions differed significantly from the constant velocity conditions whose velocity matched the final velocity in the nonconstant conditions. This result pattern is in line with recent data showing that CT response bias increases when velocities are either accelerating or decelerating (e.g., Benguigui et al., 2003).

With regard to aging, the results confirmed previous studies showing that older adults have trouble synchronizing their responses with moving objects (Haywood,
They also showed that older adults had more trouble than their younger counterparts in the accelerating and decelerating conditions. In addition, this age-related impairment, whether at nonconstant or constant velocities, continued to rise as age rose from 60-70 to 70-80 years. These results are only applicable to men, however, because there were no female participants. Given that studies on how age affects CT skills have used either men (e.g., Christensen et al., 2003; Fleury & Bard, 1985; Haywood, 1980) or women (e.g., Del Rey, 1982; Meeuwsen et al., 1997), comparing participants of the two genders would provide a more general understanding of the effects of aging on CT actions.

Perceptual deficits are usually proposed to account for the difficulty of older adults in CT tasks (Haywood, 1980; Meeuwsen et al., 1997). However, in this study, the older adults cannot be said to have had more trouble using acceleration information, because the younger adults did not use acceleration either, as revealed by a similar response bias in the nonconstant velocity conditions for all age groups (see also Benguigui et al., 2003). Instead, we suggest that older adults are affected more by nonconstant velocities because of a perceptuomotor deficit (i.e., their greater VMD). This hypothesis was supported by the second experiment in which older adults were found to have a longer VMD than younger ones, as noted by Bennett and Castiello (1995) and Warabi et al. (1986). It was also validated by the significant correlation between the actual errors in the nonconstant conditions (see Experiment 1) and the errors predicted on the basis of VMD.

Meeuwsen et al. (1997), who examined CT accuracy in two tasks with different motor complexity levels, already noted the perceptuomotor deficit identified in this study. Two age groups of young ($M_{age} = 22.9$ years) and older ($M_{age} = 75$ years) adults were tested in both a simple switch-pressing task and a more complex hitting task. The latter task consisted of using a stick to hit a barrier so that it would press a microswitch at the same time a stimulus arrived at a target. Whereas younger adults performed the two tasks in the same way, the older participants’ response bias was greater in the CT task and increased with motor complexity, suggesting perceptuomotor and motor impairment. These deficits can be compared to those found in a study by Bennett.

### Table 3. Predicted CE (calculated from VMD) and actual CE for each group in the accelerating and decelerating conditions

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>Predicted CE from the VMD length</th>
<th>Actual CE</th>
<th>OE*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CE-Acc</td>
<td>CE-Dec</td>
<td>OE*</td>
</tr>
<tr>
<td>Players</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20–30</td>
<td>13</td>
<td>-26</td>
<td>39</td>
</tr>
<tr>
<td>60–70</td>
<td>15</td>
<td>-31</td>
<td>46</td>
</tr>
<tr>
<td>70–80</td>
<td>17</td>
<td>-34</td>
<td>51</td>
</tr>
<tr>
<td>Nonplayers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20–30</td>
<td>15</td>
<td>-30</td>
<td>45</td>
</tr>
<tr>
<td>60–70</td>
<td>18</td>
<td>-37</td>
<td>55</td>
</tr>
<tr>
<td>70–80</td>
<td>20</td>
<td>-41</td>
<td>61</td>
</tr>
<tr>
<td>Mean</td>
<td>16</td>
<td>-33</td>
<td>49</td>
</tr>
</tbody>
</table>

Note. CE = constant error; VMD = visuomotor delay; CE-Acc = constant error in the accelerating velocity condition; CE-Dec = constant error in the decelerating velocity condition; OE = overall error.

*OE corresponds to the difference between the CEs in the accelerating and decelerating conditions. Note that the mean OE predicted from VMD (49 ms) is exactly equal to the mean OE observed in the data.
and Castiello (1995), who used a stationary-object pre-
prehension task and showed that older adults needed more
time to adapt their movement to unexpected changes.

In contrast to these negative effects of age, no dif-
ference on response timing appeared between the
younger and older tennis players when nonconstant
velocities were presented. This result is consistent with
data showing that playing a sport (such as tennis or golf;
e.g., Spiriduso & Clifford, 1978), doing physical exercise
(e.g., Rikli & Edwards, 1991), or practicing (e.g., Light,
Reilly, Behrman, & Spiriduso, 1996) may slow down age-
related effects on a number of sensorimotor functions.
Physical exercise has also been shown to reduce the ef-
fects of age on CT performance in older adults who re-
main physically active (Christensen et al., 2003; Del Rey,
1982; Haywood, 1980). Our study showed in addition that
the typical effects of aging can be completely eliminated
by lifelong practice of an activity involving CT processes.
Similar results have been reported previously, but only in
older adults who were regarded as experts in their activity
(e.g., typing: Bosman, 1993; chess or bridge playing:
The fact that the participants we selected were not experts
but only recreational players should be considered in view
of improving the well being of older adults.

The question that arises from these results concerns
the origin of sustained accuracy in older recreational
tennis players. Again, the results of the second experi-
ment provide an alternative to the classical interpreta-
tions. First, the effect of playing tennis here was that our
older tennis players had shorter VMDs than our older
nonplayers. Second, the significant correlation between
the observed OE and the errors predicted from VMD
length showed that participants who had the shortest
VMDs (younger participants and older tennis players)
were less affected by nonconstant velocities than older
nonplayers. These data argue in favor of the idea that
tennis playing has a beneficial effect on CT accuracy,
because it maintains a short VMD.

In summary, our study offers the important finding
that VMD plays a role in CT tasks, making it a good can-
didate to explain the CT response bias. Whereas pre-
vious studies focused on the well established effects of aging
on perceptual processes, our findings strongly suggest
that more attention should be paid to perceptuomotor
processes in CT performance. With regard to the ob-
erved age effects, the present results confirm the conclu-
sion drawn by others (Haywood, 1980; Meeuwsen et al.,
1997), that older adults are impaired in tuning their re-
sponses to a moving object. In addition, we showed that
older adults were also impaired when the stimulus ve-
locity was not constant, a finding never obtained so far.
Furthermore, our hypothesis, that age effects can be
eliminated and not merely reduced by a ball-sport activ-
ity involving CT processes, was validated.

The encouraging relationship between aging, ten-
nis playing, and CT accuracy should be studied in more
ecological activities to promote the autonomy of older
adults and find ways to maintain that autonomy as long
as possible.

References

on the coincidence timing accuracy of adults and chil-
contact estimation of accelerated stimuli is based on first-
order information. Journal of Experimental Psychology: Human
Perception and Performance, 29, 1083–1101.
prehension components following perturbation of ob-
ject size. Psychology and Aging, 10, 204–214.
tion about time to collision between two objects. Journal of
Experimental Psychology: Human Perception and Perfor-
ance, 19, 1041–1052.
Bosman, E. A. (1993). Age-related differences in motoric as-
pects of transcription typing skill. Psychology and Aging, 8,
87–102.
of movement. In L. Proteau & D. Elliott (Eds.), Vision and
motor control (pp. 3–31). Amsterdam: Elsevier Science
Publishers.
latencies during discrete arm movement. Journal of Mo-
tor Behavior, 19, 333–354.
Life in the lab. In T. M. Hess (Ed.), Aging and cognition:
Knowledge organization and utilization (pp. 343–386).
Christensen, C. L., Payne, V. G., Wughalter, E. H., Yan, J. H.,
Henehan, M., & Jones, R. (2003). Physical activity, physi-
ological, and psychomotor performance: A study of vari-
ously active older adult men. Research Quarterly for Exercise
and Sport, 74, 136–142.
Del Rey, P. (1982). Effects of contextual interference on the
memory of older females differing in levels of physical
complexity as determiners of coincident timing behav-
across the life span. Experimental Aging Research, 6, 451–462.
in nonconstant optical flow fields. Perception and Psycho-
physics, 57, 817–825.
Lee, D. N. (1976). A theory of visual control of braking based
Lee, D. N., Young, D. S., Reddish, P. E., Lough, S., & Clayton, T.
Notes

1. The optical variable tau is defined as the quotient of the optical size and the optical-size dilation rate in the case of head-on or radial approaches, and by the quotient of the relative optical-gap constriction rate that separates the moving object and the target position in tangential approaches (paths not leading to the observer; Bootsma & Oudejans, 1993; Lee, 1976; Tresilian, 1990, 1991).

2. Because the same participants took part in the CT and stop-signal experiments (making a total of 190 CT trials), the number of trials in the CT experiment (nonconstant or constant velocities) was voluntarily limited in an attempt to reduce the impact of attention requirements on performance. Note that this number of trials is commonly used in CT experiments (e.g., 10 trials per velocity condition in Haywood, 1980).

3. Absolute error (AE), which corresponds to the error regardless of its direction and provides a measure of overall task accuracy, was also calculated. This dependent variable is commonly used in CT tasks. However, we did not report it because the overall accuracy given by AE was only of minor interest here, where our specific concern was the link between acceleration and response bias.

4. The same participants performed Experiments 1 and 2 that were presented in counterbalanced order: half of the participants in each group performed the CT task followed by the stop-signal task, and the other half of the participants in each group performed the stop-signal task followed by the CT task.

5. In these statistical results, two participants were eliminated from the analysis because they were detected as outliers (i.e., extreme cases that fell outside +/- 2.5 standard deviations).

Authors’ Note

This research was supported by a grant from the French Ministry for Research and Education to the first author while he was with the Center for Research in Sport Sciences, Faculty of Sport Sciences, University of Paris-Sud, Orsay, France. The authors are grateful for the interest and cooperation shown by the participants in the study. They wish to thank the different organizations for their assistance in recruiting participants. Please address all correspondence concerning this article to Régis Lobjois, Institut National de Recherche sur les Transports et leur Sécurité, Laboratoire de Psychologie de la Conduite, 2, Avenue du Général Malleret-Joinville, Arcueil, France 94114.

E-mail: lobjois@inrets.fr