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# The Effect of Aging and Tennis Playing on Coincidence-Timing Accuracy

**Régis Lobjois, Nicolas Benguigui, and Jean Bertsch**

This study examined the effect of tennis playing on the coincidence timing (CT) of older adults. Young, younger-old and older-old (20–30, 60–69, and 70–79 years old, respectively) tennis players and nonplayers were asked to synchronize a simple response (pressing a button) with the arrival of a moving stimulus at a target. Results showed that the older tennis players responded with a slight bias similar to that of the young players. Two experiments were conducted to determine whether the elimination of age effects through tennis playing was a result of maintaining basic perceptuomotor and perceptual processes or of some possible compensation strategy. The results revealed that the age-related increase in the visuomotor delay was significantly correlated with CT performance in older nonplayers but not in older tennis players. These results suggest that playing tennis is beneficial to older adults, insofar as they remained as accurate as younger ones despite less efficient perceptuomotor processes. This supports the compensation hypothesis.

***Key Words***: ■

Adapting one's responses to environmental constraints becomes increasingly difficult and demanding with age. In situations that require accurate coordination with a moving object, such as driving an automobile or crossing a road, both drivers and pedestrians over 60 years of age have been found to be at a greater risk of accidents (Owsley, Ball, Sloane, Roenker, & Bruni, 1991; Oxley, Fildes, Ihsen, Charlton, & Day, 1997). Declining perceptual and motor skills have been advanced as a plausible cause (e.g., Stelmach & Nahom, 1992). Perceptual and perceptuomotor processes can be studied in coincidence-timing (CT) tasks, which consist of synchronizing simple responses (pressing a button) with the arrival of a moving object at a target. To be successful in such tasks, the actor must first determine when the moving object will reach the target point in space. This is the perceptual component of the task, which is the most important one because the motor response is minimal. Then the actor must coordinate his or her motor response with the object's approach based on that information. This is the perceptuomotor component of the task. Studies investigating CT skills with age have revealed significant performance decreases in older groups (e.g., Meeuwsen, Goode, & Goggin, 1997).

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Some questions that arise concern the causes of such changes and how uncoordinated responses might be reduced by factors such as physical exercise or sports. Few studies, however, have looked at the effects of age and playing sports on CT performance. The purpose of our study was to find out whether playing a specific sport, such as tennis, in which CT processes are predominant can eliminate the effects of age, and, if so, determine how older tennis players manage to perform as accurately as younger ones.

## Aging and CT

In CT tasks, adults over 60 years of age perform with greater overall error and variability than younger adults (Haywood, 1980; Lobjois, Maquestiaux, Benguigui, & Bertsch, 1999; Meeuwsen et al., 1997). In addition, they have two different response patterns that are of practical importance because they might have direct impact on everyday activities. Older adults have been shown to systematically produce delayed responses and to be increasingly affected as stimulus velocity rises (Haywood, 1980; Meeuwsen et al.).

In a study on CT actions involving an impulse type of control (e.g., pressing a button), Benguigui, Ripoll, and Broderick (2003) suggested that participants have to estimate the motor-sequence duration (including the visuomotor delay [VMD] and the movement time) and initiate their response when the stimulus arrival time becomes equal to that duration. VMD is generally defined as the time between when information is registered and the resulting observable movement events (e.g., Benguigui et al.; Carlton & Carlton, 1987; Tresilian, 1993). Perceptuomotor integration is thus necessary to account for this delay between sensory input and motor output. Accuracy in CT would therefore depend on the ability to correctly integrate VMD in the response duration (e.g., Abernethy & Burgess-Limerick, 1992; Benguigui & Ripoll, 1998) or on the VMD shortness (Tresilian, 1995). On this point, Bennett and Castiello (1995) showed using a grasping task that VMD was as high as 232 ms for the elderly (mean age = 66), that is, 62 ms longer than for younger adults (for a similar result see also Warabi, Noda, & Kato, 1986). Thus, a potential explanation for older adults' late responses in CT tasks would be an age-related increase in VMD. More important, this increase could be coupled with difficulty integrating the longer delay into the motor-response duration when response is executed.

Regarding the age-related differential effect of stimulus velocity, Haywood (1980) demonstrated an overall tendency in older adults (mean age = 67.5) to perform with increasingly delayed responses as speed increased (from 1.34 to 2.23 m/s) whereas younger participants (mean age = 22.8) were not affected by this factor. This result was confirmed by Meeuwsen et al. (1997) for three different speeds (1.79, 3.58, and 5.37 m/s). To explain the greater and greater impact of velocity with age, it has been mainly suggested that older participants perceive the speed of a moving object less accurately (e.g., Haywood, 1980). To further explain this effect, one can refer to developmental studies in which a similar velocity effect was observed (i.e., smaller error and very late responses to slow and fast velocities, respectively, as compared with the intermediate velocity-response bias; eg, Haywood, 1983; Stadulis, 1985). It has been suggested that this effect is linked to the use of an assimilation or ranging strategy because of the less accurate discrimination of velocities across trials. Observers using this strategy are thought to compensate for their inaccuracy by calibrating their responses to a "standard" or "mean" trajectory, which takes into account the different velocities without reference to the specific properties of each trajectory (Gagnon, Bard, & Fleury, 1990; Haywood, Greenwald, & Lewis, 1981; Smeets & Brenner, 1995). The error distribution of elderly participants observed by Haywood (1980) and Meeuwsen et al. is consistent with this hypothesis. Compared with the late-biased responses at intermediate velocities, older participants appear to be less late and later to slow and fast velocities, respectively.

## Aging, Sports, and CT

In contrast to the negative effects of age, there is evidence that older adults remain able, under certain circumstances, to perform as well as younger ones. Practice, knowledge, and experience increase with age and can reduce or even eliminate age-related declines (Fisk & Rogers, 2000). There are very few studies on how playing sports affects CT accuracy in the elderly. Del Rey (1982) and Christensen et al. (2003) showed that older adults who had remained physically active were more accurate and consistent in CT tasks than sedentary older adults. Haywood (1980) had shown earlier, however, that active older adults were less accurate than active younger ones. This last result suggests that physical exercise only moderates age deficiencies, so it would therefore be useful to test for the effect of a regular sporting activity, such as tennis, in which CT processes are critical. Sustained regular activity could eliminate the aging effect on CT accuracy. If so, determining the relationship between sports playing and CT processes could be of practical importance.

Two main hypotheses have been put forward to explain the beneficial effects of practice in the elderly. According to the preservation hypothesis, older and younger adults perform equally well because the required processes are maintained at an efficient level by task-relevant practice (Marquié, 1997; Salthouse, 1987, 1990a, 1990b). This allows equivalent degrees of competency to be achieved with the same combination of abilities at all ages (e.g., Morrow, Leirer, Altieri, & Fitzsimmons, 1994).

According to the compensation hypothesis, the negative effects of aging on normal behavior can be counteracted by practiced activities, because a loss in one area of the required processing is offset by a gain in another area (Bäckman & Dixon, 1992; Marquié, 1997; Salthouse, 1987, 1990a, 1990b, 1995). One important outcome of this type of compensation is that older adults might be able to achieve the same level of proficiency as younger ones by using different processes (e.g., Bosman, 1993; Salthouse, 1984).

The goal of the present study was to test the hypothesis that playing tennis can eliminate age-related effects on CT accuracy. We expected older individuals who played tennis on a regular basis to maintain an accuracy level similar to that of younger adults in a simple CT task. We hypothesized that they would not respond late and would not be more affected by the use of different velocities than younger adults were. We also carried out two experiments to determine whether the potential disappearance of age effects brought about by playing tennis was a result of the maintenance of basic perceptuomotor or perceptual processes or to some sort of compensation strategy. These two additional experiments were also aimed at finding a new explanation for the negative effects of age on CT performance by investigating two other possible effects: the role played by VMD in the elderly's late responses and the role played by the ability to discriminate velocities in their declining accuracy with increasing stimulus velocity.

# Experiment 1: Coincidence-Timing Task

## Methods

***Participants.*** Three age groups (20–30, 60–69, and 70–79 years of age) with two different levels of tennis experience (tennis players and nonplayers) participated in this experiment. All groups contained 10 male participants. By examining three age ranges, our aim was to compare two different older adult age groups (60–69 and 70–79) and extend previous results in which only one older group was tested (e.g., Fleury & Bard, 1985; Haywood, 1980; Meeuwsen et al., 1997), in order to gain insight into CT performance changes in the course of aging (see Table 1 for the mean age and *SD* of each group). The younger groups were composed of students, and the older groups, of retired individuals who were living on their own.

The nonplayer groups had no previous or current experience in tennis or other ball games. Among the younger nonplayers, 7 reported that they participated regularly in a physical activity (climbing, swimming, or a martial art). The older nonplayers were recruited from retirement organizations. More than half of them (6 in each age range) reported that they still did physical exercise for 1–4 hr/week. Among the younger of these older nonplayers (i.e., age 60–69, hereafter called the younger-old group), 3 walked, 2 swam, and 1 ran. Among the older ones (i.e., age 70–79, hereafter called the older-old group), 4 walked, 1 ran, and 1 cycled.

The tennis players were recruited from tennis associations. To be eligible for the study, they were required to have played tennis for 2–4 hr/week for at least 10 years (Table 1). With this much practice, one can assume that the concerned perceptual and perceptuomotor processes had been repeated thousands of times. 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; they had not even been very good amateur players in their youth. We recruited tennis players who played on a regular basis and who had experience but were not "experts" in the game because our goal was to study the effects of "social" (recreational) playing in older tennis players rather than in those with expertise.

Questionnaires were administered to the participants to determine their level of education (years) and their self-rated health status, assessed on a scale ranging from 7 (*excellent health*) to 1 (*very poor health;* see Table 1). Age × Tennis Playing analyses of variance (ANOVAs) indicated a main effect of age on education, $F(2, 54) = 19.35$, $p < .001$, both older groups having less education than the younger group. Players and nonplayers did not differ in educational level. The ANOVA on self-rated health showed no significant difference between the groups. Players and nonplayers did not differ in self-rated health.

**Table 1 Demographic Variables for Each Group**

| | Players | | | | | | Nonplayers | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Young | | Younger-old | | Older-old | | Young | | Younger-old | | Older-old | |
| Variable | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Age | 23.5 | 2.7 | 65.7 | 3.4 | 76.4 | 3.4 | 25.7 | 3.8 | 65.3 | 2.1 | 73.7 | 2.5 |
| Tennis playing (years) | 14.7 | 3.5 | 29.7 | 15.2 | 34.5 | 17.8 | — | — | — | — | — | — |
| Education (years) | 19.4 | 1.8 | 14.8 | 3.8 | 14.5 | 3.3 | 19.3 | 2.3 | 14.4 | 3.0 | 14.1 | 2.6 |
| Self-rated health | 5.2 | 1.2 | 4.9 | 1.1 | 4.7 | 1 | 5.2 | 1 | 4.7 | 1.2 | 4.5 | 1.2 |

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

***Experimental Design and Task.*** The experimental display (Figure 1) was composed of a runway of red 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 and off of 200 LEDs placed at 2-cm intervals.

Participants sat 4 m away from the runway, facing the target, with a two-button response panel on the table in front of them. Once informed of the appearance point of the stimulus, they started each trial by pressing the left button with the left hand. To respond, they were required to press the right button with the right hand in order to make their response coincide with the arrival of the moving object at the end of the runway. The time between a participant's response and the lighting up of the last LED was the measure of response accuracy (in ms). Participants performed the task at three different speeds: slow (1.77 m/s), intermediate (3.55 m/s), and fast (5.33 m/s). The viewing time was identical in all conditions (750 ms). Whereas in past studies (Haywood, 1980; Meeuwsen et al., 1997) the viewing time decreased as velocity increased (from 1.12 to 0.68 s and from 1.26 to 0.42 s for each study mentioned above, respectively), the present investigation held the viewing time constant while varying velocity. This was to ensure that the expected response patterns were a result of the velocity manipulation and not of the viewing time.

***Procedure.*** After the experimenter's explanation, a training session consisting of 15 randomly presented trials at three different velocities (1.4, 2.8, and 4.2 m/s) was held. During this session, feedback about temporal accuracy (size and direction of error) was given (in milliseconds) to the participants after each trial. During

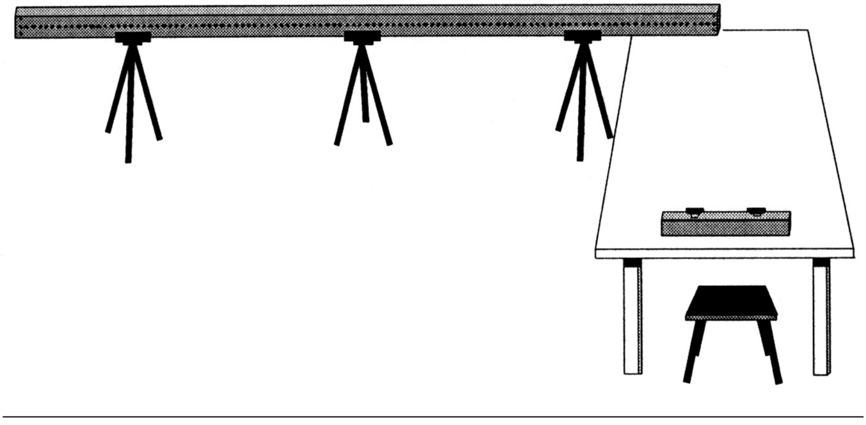

**Figure 1** — Experimental setup.

the experimental session, participants performed eight trials per velocity condition (making a total of 24) and the velocity order was randomized. Corrective feedback (in milliseconds) was also given after each trial during data collection.

## Results

For each participant and each condition, constant error (CE) and variable error (VE) were calculated.[1] CE was the algebraic mean of the error, which was equal to the difference between the actual arrival time of the stimulus and the participant's response. CE scores indicated the directional bias of the responses (early responses had a negative sign; late responses had a positive sign). VE was equal to the *SD* of the errors and indicated the response dispersion. An ANOVA was carried out on CE and VE, with age group (young, younger-old, and older-old) and tennis playing (players and nonplayers) as between-subjects factors and stimulus velocity (slow, intermediate, and fast) as a within-subject factor.[2] Significance was set at .05. Exact probabilities and the effect sizes ($\eta^2$) are reported. Significant differences were further examined using Newman–Keuls post hoc test when necessary. The same criteria were used in the statistical analysis of the two subsequent experiments.

The results for the CE scores in the Age Group × Tennis Playing × Velocity design are presented in Figure 2, which shows all results including ones that were nonsignificant but important for understanding the effects. The analysis yielded a significant main effect of age group, $F(2, 54) = 10.07$, $p < .001$, $\eta^2 = .27$. CE was lower for younger adults ($M = –4$ ms) than for younger-old adults ($M = 11$ ms) and older-old adults ($M = 16$ ms), who did not differ significantly from each other. There was a significant main effect of tennis playing, $F(1, 54) = 15.35$, $p < .001$, $\eta^2 = .22$, because of a smaller CE for players ($M = 1$ ms) than for nonplayers ($M = 15$ ms). The effect of stimulus velocity was also significant, $F(2, 108) = 15.40$, $p < .001$, $\eta^2 = .22$. CE was lower at the slow ($M = 3$ ms) and intermediate ($M = 4$ ms) velocities than at the fast ($M = 16$ ms) velocity. There was a significant two-factor interaction between age group and tennis playing, $F(2, 54) = 3.26$, $p = .046$, $\eta^2 = .11$. Post hoc comparisons yielded no age-related difference in the player groups ($M = –8$, 6, and 2 ms for the younger, younger-old, and older-old groups, respectively), whereas the older-old nonplayers ($M = 31$ ms) differed significantly from the younger and younger-old nonplayers ($M = –1$ and 16 ms, respectively). Note that the younger nonplayers did not differ from the younger players. There was also a significant interaction between age group and velocity, $F(4, 108) = 4.67$, $p = .002$, $\eta^2 = .15$. The younger group showed a slight tendency to respond early, and this bias did not change with velocity ($M = –1$, –10, and –2 ms for the slow, intermediate, and fast velocities, respectively). In both older groups, CE increased with velocity, leading to late-biased responses. Compared with the younger adults, the younger-old group performed similarly on the slowest velocity ($M = –1$ ms) but differed significantly for the two faster velocities ($M = 11$ and 23 ms for the intermediate and fast velocities, respectively). The older-old group differed from both other groups on the slow velocity ($M = 12$ ms), but the response pattern resembled that of the younger-old group for the intermediate ($M = 11$ ms) and fast ($M = 26$ ms) velocities. Finally, the interaction between tennis playing and velocity, $F(2, 108) = 8.00$, $p = .001$, $\eta^2 = .13$, was also significant. Although the players were not affected by the velocity manipulation ($M = 10$, –4, and 3 ms for the slow, intermediate, and fast velocities, respectively), CE increased significantly with velocity for nonplayers ($M$ = 6, 12, and 28 ms for the three velocities, respectively). The three-factor interaction between age group, tennis playing, and velocity fell short of significance, $F(2, 108) = 1.69$, $p = .158$, $\eta^2 = .06$.

The results for VE are presented in Figure 3, which represents the full Age Group × Tennis Playing × Velocity design. The VE analysis revealed a significant main effect of age group, $F(2, 54) = 11.78$, $p < .001$, $\eta^2 = .30$; VE was the lowest for young adults ($M$ = 22 ms, $SD$ = 6 ms), intermediate for younger-old adults ($M$ = 33 ms, $SD$ = 14 ms), and the highest for the older-old adults ($M$ = 37 ms, $SD$ = 14 ms). There was also a significant main effect of tennis playing, $F(1, 54) = 14.30$, $p < .001$, $\eta^2 = .21$, because of a smaller VE for tennis players ($M$ = 26 ms, $SD$ = 6 ms) than for nonplayers ($M$ = 36 ms, $SD$ = 15 ms). The interaction between age group and tennis playing was nonsignificant, $F(2, 54) = 2.99$, $p = .059$, $\eta^2 = .10$. The player groups did not differ from each other ($M$ = 22, 26, and 29 ms, $SD$ = 5, 6, and 8 ms for each age group, respectively). VE was lower, however, for the younger than for the younger-old nonplayers, who were in turn less variable than the older-old nonplayers ($M$ = 23, 39, and 45 ms, $SD$ = 8, 19, and 19 ms for the three age groups, respectively).

One might think that the interaction between age and tennis playing on CE came from other variables such as physical activity rather than tennis playing. To test for this possibility, a subgroup of the original sample was set up containing the active older non–tennis players, that is, the older adults who reported that they were still doing physical exercise (6 in each age range). An ANOVA was performed on CE, with two age groups (younger-old and older-old) and two active groups (non–tennis players who were active and tennis players) as between-subjects factors and three velocities (1.77, 3.55, and 5.33 m/s) as a within-subject factor. The result

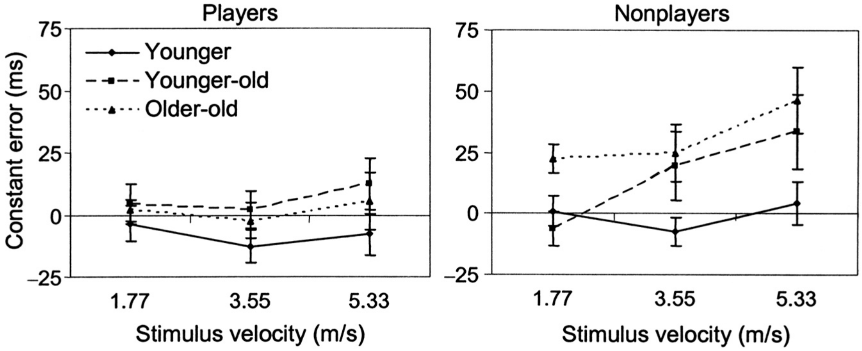


**Figure 2** — Constant error (ms) as a function of age group (20–30, 60–69, and 70–79 years) and stimulus velocity (1.77, 3.55, and 5.33 m/s) for tennis players and nonplayers in Experiment 1. Bars indicate the standard error.

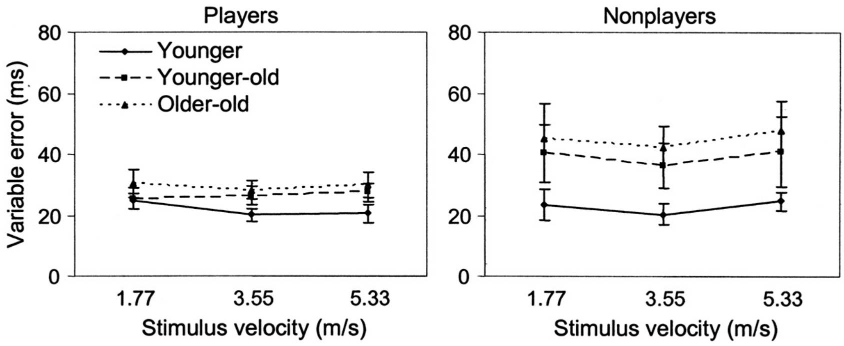


**Figure 3** — Variable error (ms) as a function of age group (20–30, 60–69, and 70–79 years) and stimulus velocity (1.77, 3.55, and 5.33 m/s) for tennis players and nonplayers in Experiment 1. Bars indicate the standard error.

of interest here was the significant difference obtained between active non–tennis players and tennis players, $F(1, 28) = 14{,}47$ $p < .001$, $\eta^2 = .34$. Given that the two active groups were engaged in different types of exercise but a similar level of activity (i.e., several hours a week for at least 10 years), this result argues in favor of a specific effect of tennis playing on CE.

## Discussion

The goals of this experiment were to replicate examinations of the effects of age on CT performance and to determine whether a CT-related activity such as tennis playing could eliminate performance declines that are typical of aging in CT tasks. Our results again supported the deteriorating effects of age on CT performance and the two different response patterns found in inactive older adults, that is, systematic late responses and sensitivity to stimulus velocity. They included the additional finding that these age-related deficits continue to rise as age increases from 60–69 to 70–79 years, as revealed by the two-factor interactions. Our prediction that CT performance would be maintained in older tennis players was supported by the results, which raises the questions of what causes this maintained performance and how it might be explained.

## Response Bias

Although the nonplayers responded increasingly late as a function of age, confirming previous results (Haywood, 1980; Meeuwsen et al., 1997), the elderly tennis players did not respond late. As suggested in the introduction, the older adults' systematically late responses could be directly linked to a greater VMD and to the inability to correctly integrate a longer delay into the response. These assumptions are supported by Bennett and Castiello's (1995) findings, which showed that VMD increases significantly with age. Playing tennis could eliminate the effect of age either by maintaining VMD or by enabling older tennis players to integrate a longer delay into their response. This tennis-playing effect can be explained by the preservation hypothesis (VMD stability), the compensation hypothesis (better integration of a longer VMD), or both (better integration of a barely higher VMD ). These hypotheses were addressed in Experiment 2, in which the VMD length of tennis players and nonplayers (of the same age ranges as in Experiment 1) was measured in a stop-signal task.

### Velocity Effect

The results also indicated a velocity effect in older nonplayers, which confirms results of previous studies (Haywood, 1980; Meeuwsen et al., 1997). Players, on the other hand, responded with a slight bias and were not affected by the velocity manipulation. The result pattern in Figure 2 strongly suggests that this was true for players of all ages, but the three-factor interaction was not significant, perhaps because of the relatively low-power design and the small number of participants in each Age Group × Player Cell.

In spite of this result, the velocity effect is worth addressing. One explanation of the velocity effect found for elderly nonplayers would be their less accurate discrimination of the various velocities, which might have caused them to use an assimilation strategy. As a result, they might have responded to the various velocities as if there was only one speed or as if the speeds were very similar. We addressed this hypothesis in Experiment 3, in which we tested the ability of tennis players and nonplayers (of the same age ranges as in Experiment 1) to discriminate among velocities.

## Experiment 2: Stop-Signal Task

Corresponding to the latency of the perceptuomotor system, the visuomotor delay (VMD) has been defined very generally as the time between the visual registering of the information needed to make an adjustment and the resulting observable movement events (e.g., Carlton & Carlton, 1987; Tresilian, 1993). Zelaznik, Hawkins, and Kisselburgh (1987) and Carlton (1992) suggested that VMD depends on the kind of task, the performer's intention and preparedness, and the performer him- or herself.

Slater-Hammel (1960) used a stop-signal procedure to study the effect of the perceptuomotor system's inertia time on response accuracy in a simple CT task. The results showed that participants ranged from always reacting on shorter time intervals to seldom reacting on longer ones. From the inhibition function (computed from the probability of responding as a function of time interval), a threshold value equal to 140 ms was defined as the time interval at which participants react 50% of the time. Because the participants were systematically late in responding on the CT task (CE = +26 ms), Slater-Hammel corrected the inertia time of the perceptuomotor system to 166 ms.

Using a similar procedure, we conducted Experiment 2 to estimate VMD in a CT task according to age and tennis playing. Our aim was to determine whether the similar CT accuracy levels of older and younger tennis players can be explained by their similar VMDs, despite aging.

## Methods

***Participants.*** The participants were the same as in Experiment 1, so we again had 6 groups ($n$ = 10) of three ages (20–30, 60–69, and 70–79) and two different levels of tennis experience (tennis players and nonplayers).[3]

***Experimental Design and Task.***The apparatus and setup were the same as in Experiment 1. To determine the VMD of each participant, a procedure similar to that of Slater-Hammel (1960) was used. Participants were asked to produce two kinds of responses, depending on the stimulus trajectory. The stimulus moving along the trajectory was either visible in its entirety until it arrived at the target or was occluded before it arrived (catch trials). When the whole trajectory was visible, participants were required to press a button at the same time that the stimulus arrived at the target in Experiment 1. On catch trials, participants were asked to inhibit their response. In these trials, the stimulus was occluded between 150 and 330 ms, in steps of 20 ms, before reaching the end of the runway, creating a total of 10 occlusion times. Longer occlusion times than Slater-Hammel's were selected because an increase in VMD was expected for the older participants.

With this procedure, the probability of responding to a catch trial was a function of occlusion time and VMD. In catch trials in which the occlusion occurred before the "last" information used to initiate the response was picked up, VMD was shorter than the occlusion time, so participants ought to be able to inhibit their responses. In contrast, in trials in which the occlusion occurred after the pickup of the "last" information, VMD was longer than the occlusion time, so participants should no longer be able to inhibit their responses. The overall probability of error (i.e., pressing the button even though the stimulus was occluded) should therefore be higher for participants with a longer VMD.

For all trials, the stimulus moved at a relatively slow velocity (2 m/s) in order to avoid late-biased responses. The viewing time for each complete trajectory was 1 s. Note that only one velocity was used in this experiment, because VMD has been shown to be independent of stimulus velocity (e.g., Benguigui et al., 2003).

***Experimental Procedure.*** First, it was explained to participants that the ability to inhibit their responses was as important as the ability to accurately press the button when the stimulus was not occluded. This explanation was given to prevent them from focusing on one part of the task and neglecting the other. The participants then performed a practice block of 20 trials that included four catch trials. For these trials, the stimulus was occluded 300 ms before it reached the end of the runway. Corrective auditory feedback was provided for CT accuracy (in milliseconds) and for the ability to inhibit the response on catch trials. During the testing session, the participants performed 150 CT trials and five catch trials per occlusion time (making a total of 50 catch trials). The trials were divided into five blocks of 40, and catch trials occurred 25% of the time in each block (i.e., 10 times), equally often for each occlusion time (i.e., once per occlusion time per block). The location and the presentation order of each occlusion time in a block were randomly distributed across groups, participants, and blocks. Corrective feedback was provided.

## Data Analysis and Results

The overall performance on catch trials is presented in Figure 4, where the probability of responding is displayed for each group as a function of occlusion time. This figure shows clearly that the probability of responding given a catch trial increased as the occlusion time decreased. This finding is common in the literature (e.g., Logan & Cowan, 1984; Slater-Hammel, 1960). The probability of responding as a function of occlusion time also depended on age group and tennis playing.

To determine each participant's VMD, the mean constant error when no catch trial was presented was added to the mean probability of responding (see Logan, 1994; Slater-Hammel, 1960). A logistic function[4] was fit to the probability of responding for each participant, and the mean was determined by calculating the occlusion time at which participants inhibited their responses 50% of the time (i.e., center of the fit function; see Figure 5 for an illustration). To avoid the possibility of over- or underestimation of VMD because of nonzero responses on the CT task,[5] VMD for each participant was obtained by adding his CE when no catch trials were presented, to the 50% point.

The ANOVA conducted on VMDs (with age group and tennis playing as between-subjects factors) revealed a main effect of age group, $F(2, 54) = 13.87$, $p < .001$, $\eta^2 = .33$; the average VMD was shorter for younger adults than for younger-old and older-old adults, who did not differ from each other. The delay was shorter for players than for nonplayers, $F(1, 54) = 12.79$, $p < .001$, $\eta^2 = .19$. The interaction

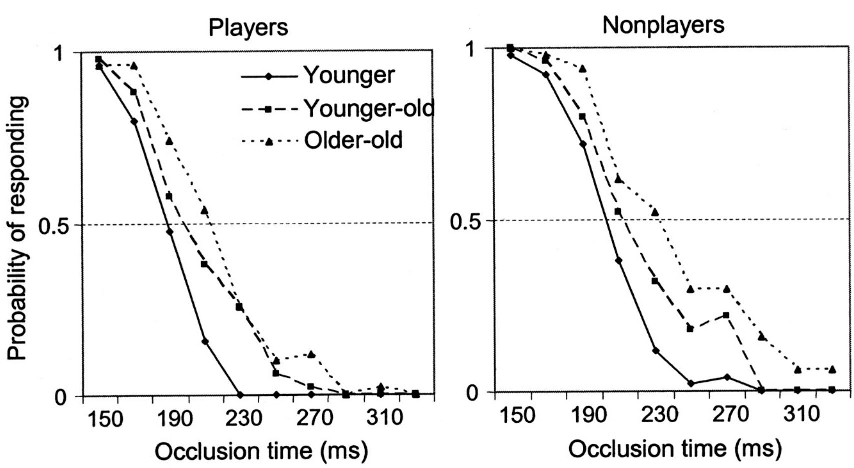


**Figure 4** — Probability of responding given a catch trial as a function of age and occlusion time for players and nonplayers in Experiment 2.

between age group and tennis playing was not significant, $F(2, 54) = 0.01$, $p = .98$. The mean and *SD* of VMD for each group are presented in Table 2.

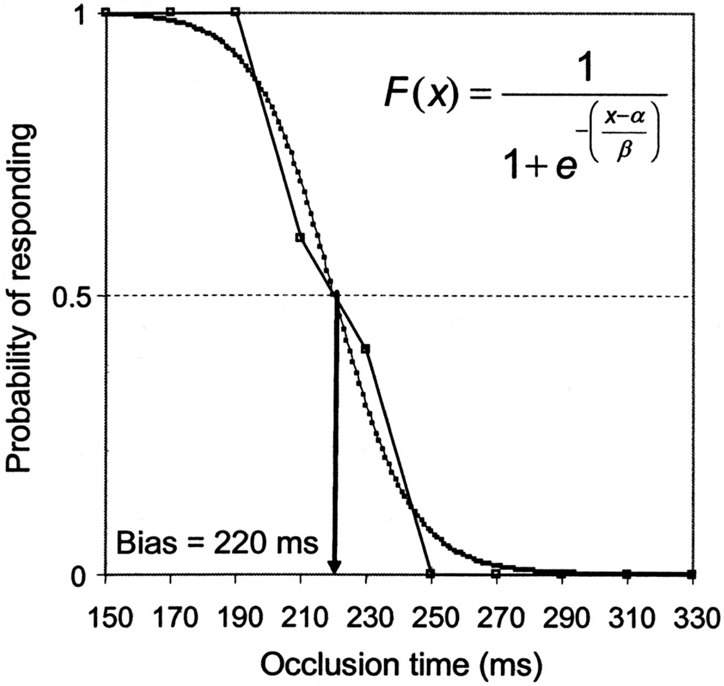


Figure 5 — Erroneous responses of a 60- to 69-year-old nonplayer as a function of the occlusion time before contact. A logistic function was fit to the probability of responding in order to estimate its mean value (the α argument of the logistic function, which corresponds to the point 0.50). For this participant, the mean was 220 ms, corrected to a visuomotor delay of 239 ms after the addition of his constant error when no catch trials were presented (+19 ms).

**Table 2 Visuomotor Delay (ms) for Each Group**

| | Players | | Nonplayers | |
|---|---|---|---|---|
| | ***M*** | ***SD*** | ***M*** | ***SD*** |
| Young | 187 | 7.91 | 204 | 14.66 |
| Younger-old | 209 | 21.44 | 224 | 17.93 |
| Older-old | 216 | 16.18 | 234 | 26.26 |

## Relationship Between VMD and the CT Bias Obtained in Experiment 1

Two regression analyses were performed for players and nonplayers, with the overall CE score in Experiment 1 (calculated by averaging the CE scores at each velocity) as the dependent variable and VMD as the independent variable. These analyses were carried out to determine whether response lateness in Experiment 1 could be explained by a VMD increase and the possible difficulty nonplayers had coping with this increase. As expected, the analyses revealed that VMD and CE were significantly correlated for nonplayers, $r^2 = .17$, $F(1, 27) = 5.85$, $p < .03$, but not for players, $r^2 = .001$, $F(1, 26) = .03$, $p = .85$ (Figure 6).[6] The low but significant correlation for nonplayers suggests that VMD lengthening might at least partially account for the bias increase on the CT task. For players, however, no link was found between VMD changes and the overall CT response bias.

## Discussion

This experiment looked at whether the age-related effect of playing tennis observed in Experiment 1 was caused by a relatively stable VMD (preservation hypothesis), to the ability to integrate a longer VMD into the response (compensation hypothesis), or to both. The preservation hypothesis would have been confirmed if the results had had the same patterns as in Experiment 1, that is, a VMD increase in

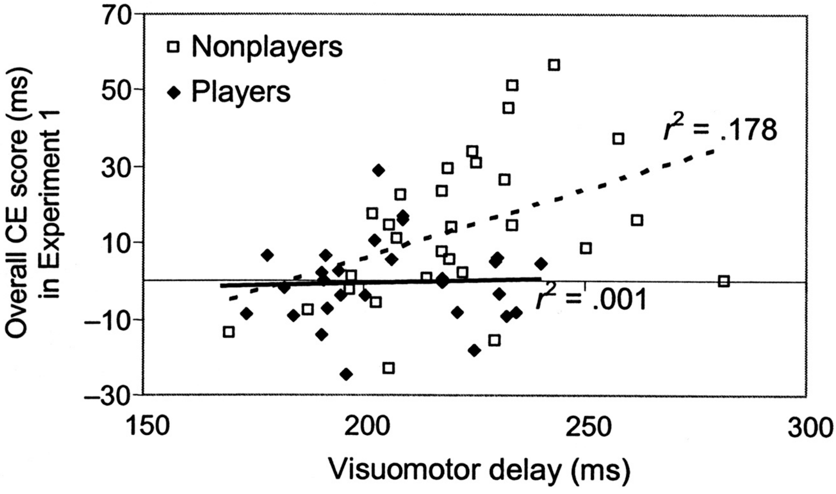


**Figure 6** — Correlation (regression line and $r^2$) between overall bias in Experiment 1 and visuomotor delay for players and nonplayers. Solid and dotted regression lines are for players and nonplayers, respectively.

older nonplayers, and substantially reduced negative age differences in players. The compensation hypothesis would have been confirmed if there had been no tennis-playing effect on older participants' VMD. The results showed that both age and tennis playing affected VMD but did not interact. The visuomotor delay increased with age, confirming previous results (Bennett & Castiello, 1995; Warabi et al., 1986), but this increase was not as great for older tennis players as it was for nonplayers. The VMD of older tennis players was not, however, as short as that of younger players.

A VMD increase seems to be a relevant factor in accounting for older nonplayers' difficulty in CT tasks and their late-responding bias. This is supported by the significant correlation obtained between the overall CT bias and VMD for nonplayers. Participants who responded late in CT tasks also had longer VMDs. Given that the age effect was not factored out of the correlation, we can be confident in saying that age-related changes account for the significant link between VMD lengthening and the CT bias increase. The difficulty with age on the CT task might therefore be a result of nonplayers' lesser ability to correctly incorporate a longer VMD into their response timing.

In contrast, no difficulty on the CT task was observed for the tennis players. The shorter VMD of older players, compared with nonplayers, might be what helps them remain accurate in CT tasks. This result partially confirms the preservation hypothesis. Older tennis players, however, also have to make up for a longer VMD. Our results thus suggest that playing tennis helps older players compensate for this deficit because they are able to maintain an average CE fairly similar to that of younger adults.

## Experiment 3: Velocity-Discrimination Task

Experiment 1 confirmed the differential effect of velocity on the response bias as a function of age and tennis playing. The velocity effect observed on older nonplayers' CE scores has been interpreted as an assimilation effect, suggesting that older participants use a standard mean trajectory to calibrate their responses, no matter what the velocity is. This strategy might be used to compensate for a decline in the ability to perceptually discriminate velocities when several trajectories are presented in the same block of trials. The aim of Experiment 3 was to assess the sensitivity of the visual system of tennis players and nonplayers at various ages in order to test the hypothesis that participants who have difficulty discriminating velocities are affected more by the velocity manipulation in CT tasks.

### Methods

***Participants, Experimental Design, and Task.*** The participants and the experimental apparatus and setup were the same as in Experiments 1 and 2.

The visual system's sensitivity to moving objects' velocities was assessed by measuring the minimum detectable difference in speed (or "just noticeable difference"), which is the discrimination threshold at which two velocities are perceived as different. The constant-stimuli method used to determine this threshold requires a two-alternative forced-choice procedure (Snodgrass, 1975). In each trial, participants had to verbally indicate whether the second of two trajectories (one reference and one variable) was faster or slower than the first. Two reference velocities were used—1.77 and 5.33 m/s, which corresponded to the slower and faster velocities in Experiment 1. The viewing time for the two reference velocities was the same (750 ms). Participants were informed of when and where the stimulus would appear. The variable velocity could be greater than or less than the reference velocity by 20%, 15%, 10%, or 5% (see Table 3 for the exact velocity-variation values). The appearance and disappearance points of the variable velocity remained the same as the reference velocity, despite the change in the viewing time (for a similar design see Brown & Bowman, 1987; see Table 3 for all viewing times by velocity condition). A change in the viewing distance of the moving stimulus would have provided an objective cue of the difference between the two velocities with the same viewing time. In addition, McKee (1981) showed that the information human observers need to detect differences in velocity is not based on variations in the total duration of the target.

***Experimental Procedure.*** First, participants performed one block of 10 training trials with 3.55 m/s as the reference velocity and two randomized variations (–20% and +20%). Corrective auditory feedback on judgment accuracy was provided. For

**Table 3 Kinematic Characteristics of the Different Trajectories Used**

| | Kinematics of the Variable Velocity | | |
|---|---|---|---|
| **Kinematics of the reference velocity** | **Velocity variation (%)** | **Velocity (m/s)** | **Duration (s)** |
| Slow speed: Speed = 1.77 m/s, | | | |
| distance = 1.33 m, duration = 0.75 s | –20 | 1.416 | 0.938 |
| | –15 | 1.505 | 0.882 |
| | –10 | 1.593 | 0.833 |
| | –5 | 1.682 | 0.789 |
| | 5 | 1.859 | 0.714 |
| | 0 | 1.947 | 0.6 |
| | 15 | 2.036 | 0.652 |
| | 20 | 2.124 | 0.625 |
| Fast speed: Speed = 5.33 m/s, | | | |
| distance = 3.99 m, duration = 0.75 s | –20 | 4.264 | 0.938 |
| | –15 | 4.531 | 0.882 |
| | –10 | 4.797 | 0.833 |
| | –5 | 5.064 | 0.789 |
| | 5 | 5.597 | 0.714 |
| | 10 | 5.863 | 0.682 |
| | 15 | 6.130 | 0.652 |
| | 20 | 6.396 | 0.625 |

the testing session, 16 experimental conditions were defined and the participants performed five trials per condition (making a total of 80). These conditions corresponded to two reference velocities (1.77 and 5.33 m/s), four variation percentages (20%, 15%, 10%, and 5%), and two variation levels (faster and slower). The variation percentage differed across blocks. The variation level could change within a block in such a way that the variable velocity could be either faster or slower than the reference velocity. For example, assuming a block with 1.77 m/s as the reference velocity and a variation of 20%, the variable velocity could be either 1.416 m/s (–20%) or 2.124 (+20%; see Table 3). Both velocities were presented five times in the block (making a total of 10 trials per block). The presentation order of the reference and variable velocities within a trial was randomized, as were the levels of variation within a block. The order of the blocks in an experimental session was also randomized. Corrective feedback was provided during the testing session.

## Data Analysis and Results

The overall performance of each group on the discrimination task is presented in Figure 7, where the probability of a "faster" response is plotted as a function of the speed variation. This figure shows that the probability of a "faster" response increased as the variable velocity ranged from 20% below the reference velocity to 20% above it. This probability was also found to depend on age and tennis playing.

To estimate the minimum difference detected by each participant for each reference velocity, a logistic function was fit to the probability of a "faster" response as a function of velocity variation (as in Experiment 2). The minimum difference was defined as half the velocity difference between 25% and 75% of the logistic

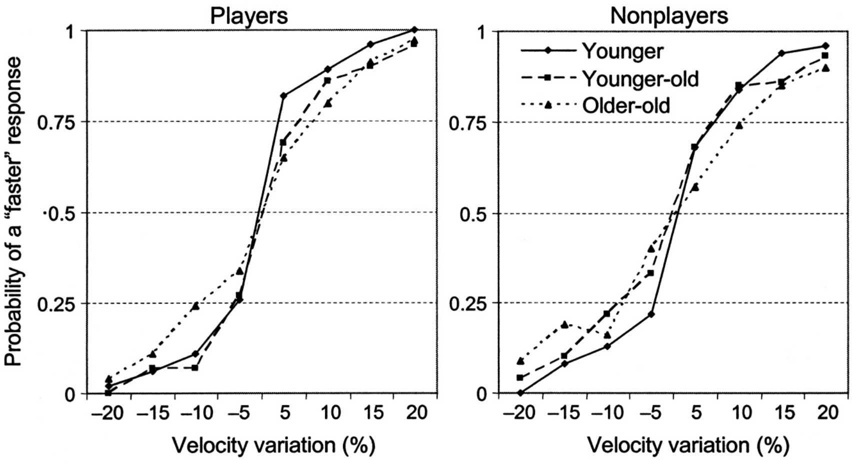


**Figure 7** — Probability of a "faster" response by age and velocity variation for players and nonplayers in Experiment 3. In this figure, probabilities at each reference velocity (i.e., 1.77 and 5.33 m/s) are collapsed.

function (the β argument). As the magnitudes of the reference velocities were different (1.77 and 5.33 m/s), Weber ratios were calculated to compare stimuli of different intensities (e.g., Snodgrass, 1975). The Weber ratio is the ratio of the minimum detectable difference to the standard magnitude. In our study, the Weber ratios for each velocity were equal to the ratio of the minimum difference to the respective reference velocity.

An ANOVA was conducted on the Weber ratios, with age group (young, younger-old, and older-old) and tennis playing (players and nonplayers) as between-subjects factors and reference speed (slow, 1.77 m/s; fast, 5.33 m/s) as a within-subject factor. The ANOVA[7] (Table 4) revealed main effects of age group, $F(2, 54) = 12.03$, $p < .001$, $\eta^2 = .31$, and tennis playing, $F(1, 54) = 7.56$, $p < .001$, $\eta^2 = .12$, but the two-factor interaction was not significant, $F(2, 54) = 0.25$, $p = .77$. Post hoc comparisons showed that younger and younger-old adults did not differ from each other, but their ratios were lower than that of older-old adults. Tennis players had a lower ratio than did nonplayers. There were no other main effects or interactions involving the velocity factor.

To test the hypothesis of a link between velocity sensitivity and the effect of velocity in Experiment 1, we performed a regression analysis with the discrimination threshold as a predictor of the magnitude of the assimilation effect. This magnitude was estimated by calculating the difference between CE scores on the slowest and fastest velocities in Experiment 1. The larger the assimilation effect, the larger the difference. For players, the difference was equal to –4, 8, and 4 ms for the younger, younger-old, and older-old participants, respectively. Similarly, it was equal to 3, 40, and 24 ms in the nonplayer groups. These means were analyzed for each group and were found to be different from 0 only for the younger-old and older-old nonplayers, $t(9) = 3.71$ and 2.65, respectively. As a result, a regression analysis was performed only for the nonplayers. It showed that discrimination threshold and assimilation-effect magnitude were not correlated,[8] $r^2 = 0.002$, $F(1, 27) = 0.7$, $p = .79$. The lack of a correlation might be a result of the fact that some participants who were accurate in velocity discrimination also demonstrated an assimilation pattern on the CT task, and vice versa.

**Table 4 Weber Ratios (%) for Each Group and Reference Velocity**

| | Players | | Nonplayers | |
|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* |
| Slow reference velocity (1.77 m/s) | | | | |
| young | 0.037 | 0.018 | 0.045 | 0.014 |
| younger-old | 0.053 | 0.024 | 0.052 | 0.037 |
| older-old | 0.071 | 0.019 | 0.103 | 0.053 |
| Fast reference velocity (5.33 m/s) | | | | |
| young | 0.041 | 0.040 | 0.059 | 0.015 |
| younger-old | 0.044 | 0.025 | 0.075 | 0.042 |
| older-old | 0.070 | 0.031 | 0.086 | 0.043 |

## Discussion

The aims of Experiment 3 were to examine the effect of age and tennis playing on the ability to perceptually discriminate velocities and to determine whether a decline in this ability could explain the assimilation effect observed in older nonplayers. Based on the results of Experiment 1, we suggested that assimilation could be used as a strategy by older nonplayers to compensate for their greater difficulty in discriminating different trajectories. The results confirmed that the ability to discriminate different velocities was not as good in older participants. Nonetheless, the lack of a correlation between the extent of assimilation and the discrimination threshold in nonplayers suggests that there is no causal link between the ability to discriminate velocities and the velocity effect in CT tasks. Some participants were accurate in the discrimination task, yet they used an assimilation strategy in the CT task. This lack of a correlation strongly questions our assumption that the velocity effect on CT responses comes from a lesser ability to discriminate velocities.

# General Discussion

The goal of this study was to gain insight into age-related changes in the elementary processes thought to account for the well-known decrease in CT performance with age. The possibility that this decline could be compensated for with age or curbed through specific motor activities such as tennis was also investigated.

## Coincidence Timing and Aging

Experiment 1 confirmed the results of other studies (Haywood, 1980; Meeuwsen et al., 1997), namely, that older adults exhibit more variability, systematically respond late, and are affected more and more as stimulus velocity increases. In the studies by Haywood (1980) and Meeuwsen et al., these results might have resulted from the fact that viewing time decreased as velocity increased. For this reason, the error increase with velocity might simply have reflected a time limitation for older adults rather than a coincidence-timing difficulty. In the present investigation, we can legitimately contend that the similar response patterns observed in the older groups were not caused by the viewing time, because it was held constant for all velocities. To explain these results, we looked at the possibility that difficulty increases with age because of changes potentially located at two different levels.

At the perceptuomotor level, we assumed that the systematically late responses of elderly participants were caused by their greater VMD and problem integrating this delay into their response. This hypothesis was confirmed by the significant correlation obtained between CE in Experiment 1 and VMD in Experiment 2. In addition to the strict perceptuomotor deficit identified in this study, the longer duration of response execution with age might have a bearing on action timing. This was already suggested by Meeuwsen et al. (1997), who examined CT accuracy in two tasks with different motor-complexity levels. Two age groups of younger (*M* = 22.9 years) and older (*M* = 75 years) adults were tested in a simple switch-press task and a more complex hitting task (using a stick to hit a barrier so that it would press a microswitch at the same time that the stimulus arrived at a target). Whereas the younger adults performed both tasks in the same way, the older participants' response bias was greater in the CT task and increased with motor complexity. These results suggest that difficulty taking into account a longer and longer motor-output duration could also be a salient deficit facing older adults.

At the perceptual level, the greater effect of velocity with age has been interpreted in terms of the assimilation hypothesis (Haywood et al., 1981; Stadulis, 1985). The assimilation strategy is assumed to be caused by an age-related decline in the ability to discriminate different velocities. The results of our discrimination task (Experiment 3) did not support this hypothesis, however.

Another explanation for the assimilation effect could be the general difficulty of elderly people to adapt their actions when there are transformations and movements occurring in their environment. In this vein, studies on the effect of age in grasping tasks have reported different findings, depending on the immobility or mobility of the object to be grasped. For example, Bennett and Castiello (1995) showed that younger and older participants adapted their grasping movement to changes in the size of the stationary object to be grasped. In contrast, Carnahan, Vandervoort, and Swanson (1998) showed that, when the object to be grasped was moving, the kinematics of the approach phase were adjusted to object size in the younger group but not in the older one. The authors concluded that aging is associated with a reduced range of motor responses when the perceptual difficulty of the task increases. In CT tasks, older participants would use assimilation as a strategy to compensate for the lesser flexibility of their perceptuomotor system involved in adapting to an ever-changing environment.

## Effect of Playing Tennis

As expected, the results of this study indicated that older tennis players maintained good CT performance. Although older nonplayers were significantly less accurate than their younger counterparts, younger-old and older-old tennis players responded with a slight bias similar to that of younger players.

Our second and third experiments were designed to determine whether the efficiency of the basic processes involved could explain the maintained performance of older tennis players in CT tasks. We hypothesized that their accuracy level comes from preservation of a short VMD or compensation for the VMD increase by better integration of this increase into the CT response. We also hypothesized that the absence of velocity effects in older tennis players comes from their preservation of the ability to discriminate velocities.

The second experiment showed that older tennis players had shorter VMDs than older nonplayers, which partially confirmed the preservation hypothesis. Playing tennis curbs the age-related increase in VMD, and this might help maintain accuracy in CT tasks. The older tennis players' VMD was longer, however, than that of the younger players. Despite this age-related decline in VMD, their CT performance was not impaired, which supports the compensation hypothesis. Through regular participation in a relevant physical activity, the older tennis players might have learned to compensate for longer motor output by initiating their responses earlier. It would be interesting to further investigate this result by examining the effects of age and sport involvement on the timing of complex actions.

Concerning the velocity effect, our results showed that players responded with a slight but consistent bias across stimulus velocities, whereas the performance of nonplayers varied with the velocity manipulation. This was also true for older players, but the three-way interaction between age, tennis playing, and velocity was nonsignificant. In addition to greater adaptability to different velocities, the tennis players were also more accurate on the discrimination task. It was not possible, however, to make a connection between this greater accuracy and the absence of a velocity effect in the CT task for the tennis players. Unlike older nonplayers, who seem to use assimilation as a strategy for minimizing environmental constraints, older tennis players might not be affected by velocity changes because of their experience with changing stimulus velocities during tennis playing. This idea remains to be investigated.

In summary, our results suggest that playing tennis helps older adults maintain the ability to adapt effectively to changes in stimulus velocities. Whereas tennis playing did not eliminate age-related declines in the elementary processes involved in CT skills, the CT performance of older tennis players was unimpaired in comparison with their younger counterparts. This was because of their compensation for the age-related VMD increase by a greater ability to integrate this increase into response timing (for similar results regarding the compensation hypothesis, see Charness, 1979, 1981; Clancy & Hoyer, 1994). The origin of the velocity effect in older nonplayers and the absence of this effect in (older) players remain to be identified. Further work is needed to understand how older players manage to avoid using the assimilation strategy.

## Endnotes

[1]Absolute error (AE) was also calculated. It corresponds to the performance errors, its direction eliminated, and provides a measure of overall accuracy in the task. Although this dependent variable is commonly used in CT tasks, we decided to not report it for two reasons. First, the statistical analysis on AE revealed the same significant effects as those on CE. It duplicated the results observed on CE scores but did not provide more information about statistical effects. Second, we focused mainly on the systematic late responses of older adults and on the reasons for such a bias. Only CE reflected a directional bias. Thus, overall accuracy as measured by AE was only of minor interest for our purposes here.

[2]To ensure that there was no trend over trials, we also conducted an Age × Tennis Playing × Velocity × Trial (3 × 2 × 3 × 8) ANOVA on constant error, with trial as a second within-subject factor. It yielded a nonsignificant effect of trial, $F(7, 378) = 1.58$, $p = .138$, and a nonsignificant Velocity × Trial interaction, $F(14, 756) = 1.46$, $p = .117$. Neither age group nor tennis playing interacted with the trial factor.

[3]Note that the three experiments were run in the same experimental session, in an order that was counterbalanced across participants. The complete session lasted approximately 1.5 hr.

[4]The logistic function is used to fit a nonlinear function to data generated by binary response that followed a sigmoid (or S-shaped) curve. It is a classical psychophysical function and a convenient model for psychometric functions that describe human performance on sensory tasks (e.g., Treutwein & Strasburger, 1999). The logistic function was

$$F(x) = \frac{1}{1 + e^{-\left(\frac{x-a}{b}\right)}}$$

From this function, one can estimate the center (α) and slope (β) of the curve, which are basic performance descriptors. The center of the fit curve provides a measure of the mean of the psychometric function. It corresponds to the argument for a function value of 0.50 (see Figure 5). The slope of the curve is a measure of performance reliability and provides information about the just noticeable difference of the psychometric function (the dependent variable used in Experiment 3). The just noticeable difference is the smallest amount of change needed for two stimuli to be perceived as different. It corresponds to half of the difference between the arguments for function values of 0.25 and 0.75.

[5]A control analysis was run to ensure that the participants did not delay their responses in the CT task in an attempt to reduce errors on catch trials. Given that the velocities were very close in Experiments 1 and 2 (1.77 and 2 m/s, respectively), this analysis (3 × 2 × 2; Age × Tennis Playing × Velocity) compared CE on the slow velocity in Experiment 1 with CE in Experiment 2 when no catch trials were presented. The analysis indicated no difference for the young and younger-old groups between Experiments 1 and 2, but CE was significantly lower in Experiment 2 for the older-old group. This result means that participants did not delay their responses in this experiment and that they performed the CT task and catch trials independently. Although the velocities were slightly different, this result provides additional support for the assimilation hypothesis, because the response bias at one velocity (1.77 m/s) presented along with two other velocities (3.55 and 5.33 m/s in Experiment 1) was greater than the response bias at one velocity (2 m/s) presented on its own.

[6]In the statistical results reported, 1 participant was excluded from the nonplayer population and 2 were excluded from the player population because they were detected as outliers (i.e., extreme cases that fall outside the ± 2.5 *SD* range).

[7]Past studies on age differences in judging vehicle velocity have shown that older adults overestimate slower velocities and underestimate faster velocities (e.g., Schiff, Oldak, & Shah, 1992; Scialfa, Kline, Lyman, & Kosnik, 1987). These findings suggest that the velocity effect on CE in Experiment 1 for the older participants results from overestimation and underestimation of the extreme velocities used (1.77 and 5.33 m/s, respectively). To control for this possibility, we also computed the threshold value from the results of the discrimination task (i.e., the α argument of the logistic function). This value, also called the point of subjective equality in a two-alternative forced-choice procedure, is the one at which the variable velocity was perceived to be equal to the reference velocity. In other words, it gives information about how velocity might be misjudged (i.e., under- or overestimated). An ANOVA with age group and tennis playing as between-subjects factors and velocity as a within-subject factor (1.77 and 5.33 m/s) yielded only a main effect of velocity, with a tendency for the slow velocity to be underestimated and for the fast velocity to be overestimated. The possibility that older participants overestimated and underestimated the slow and fast velocities, respectively, was not supported by these results.

[8]One participant was also discarded from the nonplayer population because he was detected as an outlier (i.e., extreme case outside the ± 2.5 *SD* range).

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