Exercise Can Improve Speed of Behavior in Older Drivers

José Francisco Filipe Marmeleira, Filipe Manuel Soares de Melo, Mouhaydine Tlemcani, and Mário Adriano Bandeira Godinho

The main aim of this research was to study the effects of a specific exercise program on the speed of behavior of older adults during on-the-road driving. Twenty-six drivers (55–78 yr old) were randomly assigned to either an exercise group or a control group. The exercise program (3 sessions of 60 min/wk for 8 wk) incorporated tasks that induced the participants to respond quickly to challenging situations. On-the-road driving tasks (under single- and dual-task conditions) included measures of simple and choice reaction time, movement time, and response time. Significant positive effects were found at follow-up resulting from participation in the exercise program: Improvements were found for several measures in all driving tasks, and a composite score reflected a better general drivers’ speed of behavior. These results show that exercise can enhance speed of behavior in older drivers and should therefore be promoted.

Keywords: automobile driving, aging, reaction time, physical activity

Slowing and increasing variability of motor performance during human aging is a well-demonstrated phenomenon (Der & Deary, 2006; Hultsch, MacDonald, & Dixon, 2002; Spirduso, Francis, & MacRae, 2005). The negative effect of age on reaction time (RT) is more pronounced in tasks that have high levels of complexity (Der & Deary, 2006) and could affect the way people perform daily functional tasks such as driving a car (Spirduso et al., 2005). Research has shown that speed of behavior (i.e., RT to environmental stimuli and speed of execution) can be improved by the practice of physical activity, in both simple and choice reaction tasks (American College of Sports Medicine [ACSM], 1998; Spirduso, 2006). However, few studies have explored this potential link among older drivers.

Previous studies have established an association between speed of behavior and on-road tests (McKnight & McKnight, 1999; Odenheimer et al., 1994) or crashes (Margolis et al., 2002). Driving is a complex and interactive task involving a variety of skills and requires the ability to make appropriate and timely decisions.

Marmeleira is with the Dept. of Sport and Health, and Tlemcani, the Geophysics Center, University of Évora, Évora, Portugal. Melo and Godinho are with the Faculty of Human Kinetics, Technical University of Lisbon, Cruz Quebrada, Portugal.
The speed at which visual information is processed may be an important factor for the successful negotiation of difficult or dangerous traffic situations (Anstey, Wood, Lord, & Walker, 2005). The relevance of peripheral vision to driving has been noted in subtasks such as lane maintenance (Land & Horwood, 1995) and hazard detection (Chapman & Underwood, 1998).

Unfortunately, it has been reported that older drivers show significantly decreased visual-attention ability, reflecting a spatial constriction of the useful field of view (Ball, Beard, Roenker, Miller, & Griggs, 1988) or decreased visual information-processing efficiency (Sekuler, Bennett, & Mamelak, 2000). It is promising that previous studies have found positive effects of physical activity on visual-processing speed and divided visual attention (Marmeleira, Godinho, & Fernandes, 2009; Roth, Goode, Clay, & Ball, 2003).

Increases in RT with aging are evident when it is necessary to control attention while performing concurrent tasks. In driving, dual-task deficits have often been observed in older adults (Bherer et al., 2005; Chaparro, Wood, & Carberry, 2005). Secondary tasks appear to interfere with driving, affecting the detection of hazards and of changes in the driving scenery (Recarte & Nunes, 2003). Research has revealed that dual-task deficits can be reduced by either specific cognitive training (Bherer et al., 2005) or physical activity training (Hawkins, Kramer, & Capaldi, 1992; Marmeleira et al., 2009).

There is now strong evidence that exercise and physical activity have a significant impact on several psychological parameters (Chodzko-Zajko et al., 2009). Important support for this relationship comes from intervention studies. For instance, it has been shown that exercise promotes greater information-processing speed (Marmeleira et al., 2009; Rikli & Edwards, 1991), enhancement of attention capacity in dual-task situations (Hawkins et al., 1992), and better visual-attention skills (Roth et al., 2003). Research has also indicated that the frontal region of the brain, a region that mediates executive function, is the primary locus in which aging-related cognitive deficits are found (West, 1996) and also the locus in which physical fitness appears to exert its greatest influence (Colcombe & Kramer, 2003).

It has been proposed that physical activity is associated with changes in underlying mechanisms such as cerebral blood flow (Swain et al., 2003), cerebral structure (Colcombe et al., 2006), brain-derived neurotrophic factor (Zoladz et al., 2008), neurotransmitters (Meeusen, 2005), and gene expression patterns (Booth, Chakravarthy, & Spangenburg, 2002). The gains in cardiovascular fitness are often considered the main physiological mediator underlying the cognitive benefits of physical activity (Chodzko-Zajko & Moore, 1994; van Boxtel et al., 1997). Nevertheless, some studies have failed to obtain evidence of the relation between aerobic fitness and cognitive function (Colcombe & Kramer, 2003; Etnier, Nowell, Landers, & Sibley, 2006). Thus, the underlying mediators of the relationship between physical activity and cognitive performance have yet to be fully identified (Etnier et al., 2006).

Few investigations have explored the potential link between physical training and driving-related abilities. Recent studies have shown that forms of exercise that require demanding information processing and for which the speed of behavior is crucial could be positively transferred to driving situations (Marmeleira et al., 2009; Matos & Godinho, 2009). However, other studies (Hancock, Kane, Scallen, & Albinson, 2002) have not found any advantage of sport practitioners over
nonpractitioners in a braking-task experiment. In this context, an important question is, What type of exercise is more suitable to affect driving-related abilities? For instance, it seems reasonable to assume that exercise that incorporates activities intended to enhance speed of behavior could have a greater impact on the individual’s capacity to respond quickly to environmental stimuli during actual driving. This idea is supported in the hypothesis that for positive transfer to occur between training and transfer tasks they must involve the same cognitive-processing demands (Magill, 2003). In addition, studies that compared the individual and combined effects of physical and mental exercise interventions reported cognitive benefits to be greater for combined cognitive and aerobic training (Fabre, Chamari, Masse-Biron, & Prefaut, 2002; Oswald, Rupprecht, Gunzelmann, & Tritt, 1996).

A great deal of research has focused on elderly drivers’ crash-involvement patterns, but not on developing methods to enhance their driving-related abilities. Recently, it was reported that an exercise program developed to stress perceptive, cognitive, and physical abilities was capable of improving speed of behavior among older drivers, but measures were collected in a simulated scenario (Marmeleira et al., 2009). In this context, the main aim of this research was to study the effects of a similar exercise program on the speed of behavior of older adults during on-the-road driving.

Methods

Participants

Participants were recruited from the local community by posted flyers and local radio and newspaper announcements. The inclusion criteria were being age 55 years or more, living independently in the community, being healthy without serious cardiovascular or musculoskeletal disease, and having a valid driving license, 0.5 or greater corrected visual acuity, and normal cognitive status on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975).

Twenty-six participants fulfilled the inclusion criteria; 1 subject was excluded because of severe osteoarthritis. Computer-generated random numbers stratified by gender were used to randomize participants to either a control group (CG; 63.4 ± 6.7 years) or an exercise group (EG; 65.5 ± 6.9 years). During the entire 8-week period, the CG continued to follow normal daily activities. At the 8-week follow-up, all adults in each research group completed the posttests. The age ranges were 55–76 years and 57–78 years in the EG and CG, respectively; 9 and 8 women were in the CG and EG, respectively.

Procedures

Two instrumented cars were used in the experiments. Participants drove a Volkswagen Golf, and a research assistant drove a Fiat Uno. In the Fiat a radio-telemetry transmitter was instantly activated by the car’s electric circuit whenever the rear brake light was turned on; in the Volkswagen, the testing devices included a radio-telemetry receiver, microswitches attached to the foot pedals, and six light-emitting diodes (LEDs). The LEDs were controlled using a laptop and an interface kit. All
Exercise Effects on Speed of Behavior

signs were detected by an MP100 Biopac system (interfaced with a laptop) and processed with Acqknowledge 3.7.2 software. The signal of the accelerator was registered when it was initially released; the signal from the brake pedal was detected when it was initially depressed.

Seats, mirrors, and seat belts were adjusted before getting on the road (a rural road with little traffic). Participants were instructed to follow the leading car and maintain a close but safe distance of about 30 m (the exception was the peripheral RT task, in which the participants drove without the other research car in front). The vehicles’ speed was around 50 km/hr. One investigator seated in the back seat of the vehicle driven by the participant ensured that the design protocols were followed, namely that the sequence and time intervals between stimuli (minimum of 5 s and maximum of 16 s) were identical for all participants and that the required distance to the leading car was maintained. Participants were instructed to detect stimuli as fast as possible while keeping their attention on the road. The same investigator and research assistant conducted both the pre- and the postassessment. The institutional human research ethics committee approved this study.

Brake RT Task

Participants were instructed to brake as quickly as possible whenever the leading car’s rear brake lights were activated. The total drive time was about 6 min. Each participant had to respond to 26 onsets of the rear brake lights (2 for practice and 24 for data acquisition). Three time measures were recorded: (a) RT, measured from the onset of the leading car’s brake lights to the initial release of the accelerator by the driver participant; (b) movement time, the period from the initial release of the accelerator to the initial brake application; and (c) response time, measured from the onset of the leading car’s brake lights to the participant’s initial brake application.

Peripheral RT Task

Six red LEDs were positioned approximately 10°, 20°, and 30° left (three LEDs) and right (three LEDs) of the center of the sight line of the driver and approximately 8° above the car’s console. All the LEDs were placed in the front windshield except one in the left front door window. The LEDs have a light intensity of 10.0 cd.

The participants reacted by depressing with their left thumb a microswitch attached to the left side of the steering wheel. One LED at a time was illuminated for 2 s (less time if the microswitch was depressed sooner). The total time of the task was about 8 min. The participant had to respond to 54 onsets of the LEDs (6 for practice and 48—8 by LED—for data acquisition). Performance was recorded in the form of number of signal misses and RTs in milliseconds.

This type of task has been used before and depends greatly on divided visual attention (Wood, 2002), which is a skill frequently associated with driving performance in the elderly (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Wood, 2002).

Choice RT Task

A two-choice task was used. Participants were instructed to follow the leading car and react as quickly as possible to either of the following stimuli: (a) The
leading car’s rear brake lights were activated, or (b) one of two LEDs placed in the front windshield (20° left and right) was activated. In the first condition, the participant should brake; in the second condition, he or she should depress the microswitch on the steering wheel. The use of two LEDs instead of one was intended to target both sides of the visual field and to avoid any posture adjustments of the driver to position the LEDs in a more central region of his or her visual field.

The total time of the task was about 6 min, during which the participant had to respond to 32 stimuli (4 for practice and 28 for data acquisition). The occurrence of the two stimulus types was balanced. Performance was evaluated by the RTs and number of errors.

**Dual-Task Condition**

In the dual-task condition, the primary task was similar to the brake RT task (i.e., the participant had to brake as fast as possible whenever the leading car’s rear brake lights were activated). The time intervals between the stimulus onsets were also the same as for the brake RT task. The secondary task was a mental-calculation task that required participants to verbally report the result of adding or subtracting pairs of numbers presented by the researcher. A new pair of numbers was presented roughly every 5 s. This type of secondary task has been used frequently (Chaparro et al., 2005; Marmeleira et al., 2009). Performance measurements were similar to those of the brake RT task. It has previously been demonstrated that drivers’ ability is negatively influenced by the interference resulting from performing a nonvisual task while driving (Lamble, Kauranen, Laakso, & Summala, 1999). Dual-task paradigms have also commonly been used to investigate executive functioning (Adcock, Constable, Gore, & Goldman-Rakic, 2000).

**Exercise Intervention**

The EG participated in a supervised exercise program 3 days/week for 8 weeks. Each session lasted approximately 60 min. The exercise intervention incorporated physical tasks that induced the participants to respond to challenging situations by producing the desirable motor responses. The idea was that physical activities that make large cognitive demands may influence some aspects of cognition more than repetitive and cyclic activities (Spirduso, 2006).

The types of tasks incorporated in the intervention were very similar to those used in another study (Marmeleira et al., 2009). However, more emphasis was placed on activities intended to enhance the participants’ speed of behavior; frequently, the time needed to respond was a criterion of success. Some examples of the types of activities are tasks that target simple RT (e.g., while walking, an auditory/visual sign is presented that requires a specific psychomotor response), tasks that focus on choice RT (e.g., similar to the simple RT but including more than one auditory/visual sign), dual-task situations (e.g., walking in different directions while executing another motor task with the arms), activities that work peripheral vision (e.g., maintaining several balloons in the air), activities focused on response inhibition (e.g., while maintaining balloons in the air, all auditory numeric signs except one require rapidly catching specific-color balloons),
actions that require planning efforts and decision making (e.g., orienteering in the gymnasium and in an open space), and activities strongly depending on working memory (e.g., selecting and completing a specific walking course in the gymnasium after the presentation of the associated auditory signal, the correspondence of auditory cues to walking courses having been previously established). Cooperative games requiring a dynamic group behavior were frequently included.

It is important to emphasize that the intervention in this study could not be considered multimodal in the common view of a program with two distinct parts (mental exercise and physical exercise) that are implemented side by side with the goal of improving cognitive function in older adults. The type of program that this research advocates is clearly a physical exercise program in which cognitively challenging tasks are executed by the older adults undertaking physical activities such as walking, stepping, reaching, throwing, and manipulating objects.

Statistical Analyses

The upper bound of each time-component measurement was established by computing the mean and standard deviation separately for each participant (CG and EG, baseline and after 8 weeks) and dropping any trial exceeding the mean by 3 or more standard deviations (Hultsch et al., 2002). A lower bound for legitimate responses was set at 150 ms, and scores below this limit were dropped. To capture the overall driving performance for each participant compared with the whole group, a composite driving score was computed for the baseline and follow-up by standardizing each of the RT measures (calculating $z$ scores) from the four road tests and summing $z$ scores. To show the main effect of time, the composite driving score at follow-up was calculated using the mean and standard deviation from the baseline RT measures.

Data normality was evaluated by a Shapiro–Wilk test. An independent-sample $t$ test was used to study differences at baseline between the CG and the EG. The paired-sample $t$ test was used to compare data within each group at baseline and after 8 weeks. To assess whether the EG and CG showed differential change after 8 weeks, analyses of covariance (ANCOVAs) were conducted on the change scores (i.e., postintervention minus baseline), with baseline score serving as the covariate. Effect sizes are reported as partial eta-squared ($\eta_p^2$), with cut-off values of .01, .06, and .14 for small, medium, and large effects, respectively (Cohen, 1988). The results are expressed as $M \pm SD$. Significance was set at $p < .05$ for all tests. Data were analyzed using SPSS 15.0 for Windows (SPSS, Chicago, IL).

Results

The general groups’ characteristics (Table 1) were similar in gender, age, visual acuity, MMSE score, years with a driver’s license, and weekly physical activity as measured by the International Physical Activity Questionnaire–Short Form (Craig et al., 2003). Six participants from each group had practiced some type of exercise (mainly dance or aquatic exercise) for at least 1 year. Compliance in the exercise sessions was very good, exceeding 80% for all participants.
At baseline, the EG and CG did not show any statistical difference in the driving-related variables. However, several within- and between-groups differences were found after 8 weeks (Table 2).

In the brake RT task, significant improvements were found in the EG in RT (-8%, \( p = .008 \)) and response time (-7%, \( p = .045 \)) after 8 weeks. Intergroup analysis indicated significant differences in the 8-week changes between groups for RT (-8% for the EG and 3% for the CG): \( F(1, 24) = 6.91, p = .015, \eta_p^2 = .231 \).

In the peripheral RT task, significant improvements were found in the EG (-8%, \( p = .045 \)) after 8 weeks. In the choice RT task, significant improvements were found in the EG in RT (-7%, \( p = .018 \)) at follow-up. Intergroup analysis indicated significant differences in the 8-week changes between groups (-7% for the EG and 1% for the CG): \( F(1, 24) = 10.32, p = .004, \eta_p^2 = .310 \).

In the dual-task condition, intergroup analysis indicated significant differences in the 8-week changes between groups for response time (-7% for the EG and 1% for the CG): \( F(1, 24) = 5.08, p = .034, \eta_p^2 = .181 \).

The EG displayed significant differences compared with the CG for the magnitude of improvement on the composite score from the pre- to posttest measures: \( F(1, 24) = 12.80, p = .002, \eta_p^2 = .358 \) (Figure 1).

**Discussion**

This study is one of the few to investigate the effects of exercise on the speed of behavior of older drivers. During the training program, task constraints induced the participants to increase the speed of central mental processes (e.g., stimulus identification, response selection, and response programming) to accomplish the desired responses. Significant positive effects occurred in the simple, two-choice, and peripheral RT tasks and in the dual-task condition. Moreover, a composite score reflecting all RT measurements also showed significant improvements.
<table>
<thead>
<tr>
<th>Variables</th>
<th>Baseline,</th>
<th>8 weeks,</th>
<th>Difference between</th>
<th>( p )</th>
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<tbody>
<tr>
<td></td>
<td>( M \ (SD) )</td>
<td>( M \ (SD) )</td>
<td>means, ( M \ (95% \ CI) )</td>
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<tr>
<td><strong>Brake RT Task</strong></td>
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<tr>
<td><strong>RT</strong></td>
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<tr>
<td>control group</td>
<td>421.2 (64.4)</td>
<td>431.8 (34.2)</td>
<td>10.6 (–26.6, 47.8)</td>
<td>.015</td>
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<tr>
<td>experimental group</td>
<td>438.4 (73.5)</td>
<td>401.7 (56.4)</td>
<td>–6.7 (–26.0, –11.4)*</td>
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<tr>
<td><strong>Movement time</strong></td>
<td></td>
<td></td>
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<td>.583</td>
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<tr>
<td>control group</td>
<td>284.1 (53.4)</td>
<td>283.5 (48.6)</td>
<td>–0.6 (–19.6, 18.9)</td>
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<tr>
<td>experimental group</td>
<td>306.4 (41.0)</td>
<td>287.5 (55.3)</td>
<td>–18.9 (–53.7, 15.9)</td>
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<tr>
<td><strong>Response time</strong></td>
<td></td>
<td></td>
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<td>.083</td>
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<tr>
<td>control group</td>
<td>707.3 (91.6)</td>
<td>714.6 (71.8)</td>
<td>7.2 (–31.5, 46.0)</td>
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<tr>
<td>experimental group</td>
<td>740.5 (100.5)</td>
<td>686.4 (107.3)</td>
<td>–54.1 (–105.4, –2.6)*</td>
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<td><strong>Peripheral RT Task</strong></td>
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<td>.167</td>
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<td><strong>RT</strong></td>
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<tr>
<td>control group</td>
<td>446.6 (95.2)</td>
<td>434.8 (96.4)</td>
<td>–11.8 (–63.3, 39.6)</td>
<td></td>
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<tr>
<td>experimental group</td>
<td>415.7 (82.5)</td>
<td>381.9 (56.8)</td>
<td>–33.8 (–66.6, –0.93)*</td>
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<tr>
<td><strong>Undetected LEDs</strong></td>
<td></td>
<td></td>
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<td>.763</td>
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<tr>
<td>control group</td>
<td>1.6 (1.9)</td>
<td>1.2 (1.6)</td>
<td>–0.5 (–1.83, 0.90)</td>
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<tr>
<td>experimental group</td>
<td>1.3 (1.1)</td>
<td>1.5 (1.2)</td>
<td>0.2 (–0.49, 0.80)</td>
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<tr>
<td><strong>Choice RT task</strong></td>
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<td>.004</td>
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<tr>
<td><strong>RT</strong></td>
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<tr>
<td>control group</td>
<td>597.1 (68.2)</td>
<td>601.7 (67.7)</td>
<td>4.6 (–43.0, 52.3)</td>
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<tr>
<td>experimental group</td>
<td>560.1 (89.3)</td>
<td>519.1 (53.4)</td>
<td>–41.0 (–73.5, –8.5)*</td>
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</tr>
<tr>
<td><strong>Errors</strong></td>
<td></td>
<td></td>
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<td>.187</td>
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<tr>
<td>control group</td>
<td>2.4 (1.3)</td>
<td>2.3 (1.4)</td>
<td>–0.08 (–0.91, 0.76)</td>
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<tr>
<td>experimental group</td>
<td>3.1 (1.7)</td>
<td>3.3 (1.4)</td>
<td>0.2 (–0.43, 0.89)</td>
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<tr>
<td><strong>Dual Task</strong></td>
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<td>.059</td>
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<tr>
<td><strong>RT</strong></td>
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<tr>
<td>control group</td>
<td>607.9 (150.7)</td>
<td>615.5 (79.2)</td>
<td>7.6 (–65.3, 80.5)</td>
<td></td>
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<tr>
<td>experimental group</td>
<td>622.4 (173.3)</td>
<td>577.2 (86.2)</td>
<td>–45.2 (–110.6, 20.3)</td>
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<tr>
<td><strong>Movement time</strong></td>
<td></td>
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<td>.264</td>
</tr>
<tr>
<td>control group</td>
<td>285.8 (59.3)</td>
<td>292.0 (47.4)</td>
<td>6.2 (–11.4, 23.9)</td>
<td></td>
</tr>
<tr>
<td>experimental group</td>
<td>316.6 (40.9)</td>
<td>296.9 (49.3)</td>
<td>–19.7 (–46.2, 6.8)</td>
<td></td>
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<tr>
<td><strong>Response time</strong></td>
<td></td>
<td></td>
<td></td>
<td>.034</td>
</tr>
<tr>
<td>control group</td>
<td>890.9 (189.6)</td>
<td>917.4 (126.8)</td>
<td>26.5 (–47.1, 100.1)</td>
<td></td>
</tr>
<tr>
<td>experimental group</td>
<td>941.8 (200.6)</td>
<td>872.1 (100.3)</td>
<td>–69.7 (–154.7, 15.3)</td>
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</tr>
</tbody>
</table>

*Note. CI = confidence interval; RT = reaction time; LED = light-emitting diode. All times are given in milliseconds. The \( p \) values are for differences in the 8-week changes between groups. Analysis of covariance.

*\( p < .05 \) changes within the group. Paired-sample \( t \) test.
The need to quickly choose between different motor responses according to the stimuli presented was recurrently trained in the exercise sessions, extending the findings of a previous study in the choice RT task (Marmeleira et al., 2009). Considering that driving is carried out in changeable environments, choice RT paradigms seem particularly important in the assessment of driving-related abilities. A higher association of on-road driving performance with a complex rather than with a simple RT paradigm has been previously reported (Odenheimer et al., 1994).

The peripheral RT task performance showed small benefits from the exercise program. Some previous studies have reported that the time to react to peripheral stimuli is amenable to improvement by the practice of sports or perceptive-motor programs (Ando, Kida, & Oda, 2001), whereas others failed to demonstrate such an effect (Helsen & Starkes, 1999). In the driving-related literature, there are reports of positive effects of cognitive-processing-speed training on visual-attention paradigms that involve the presentation of simultaneous stimuli in both central and peripheral vision (Ball, Edwards, & Ross, 2007; Roenker, Cissell, Ball, Wadley, & Edwards, 2003). However, it is important to note that these studies were conducted in laboratory settings and did not measure response time but only response accuracy. One can assume that, when measurements are carried out during actual driving, some performance decrement in peripheral RT may occur as a result of a probable increase in anxiety leading to the allocation of more attentional resources to the central driving task (Janelle, 2002).

The current study did not find significant differences in the changes between groups over the 8-week period in the peripheral RT task. However, considering the significant improvement in the EG, it seems realistic to expect larger intergroup differences if the exercise program were extended in length. It is important to note
that during the intervention program, several activities were planned to focus specifically on peripheral vision; nevertheless, it is difficult to isolate their particular contribution to the peripheral RT task performance because previous research has shown that the practicing on visual stimulus in central vision can shorten the RT to stimulus in peripheral vision, and vice versa (Ando, Kida, & Oda, 2002).

The dual-task condition reflected significant effects of the training program, reinforcing previous findings that improvements in attention performance resulting from dual-task training are generalizable to new task combinations involving new stimuli (Bherer et al., 2008; Marmeleira et al., 2009). These results are very promising considering that dual-task deficits are often observed in older adults. Secondary tasks interfere with driving, affecting the detection of hazards and changes in the driving environment (Recarte & Nunes, 2003). A recent study demonstrated that performing mental calculations while driving markedly increased the average RT of elderly drivers in comparison with younger drivers (Makishita & Matsunaga, 2008). Driving leads to a greater mental workload for older drivers than for younger drivers, and this effect is exacerbated by more complex driving contexts (Cantin, Lavalliere, Simoneau, & Teasdale, 2009).

The generalized benefit from the exercise program to the on-the-road driving tests reinforces previous findings about the potential of exercise and perceptual-motor training to promote important driving-related abilities (Marmeleira et al., 2009; Matos & Godinho, 2009). This is a very positive outcome given that motor learning often shows a great specificity, with little generalization to related tasks or new environments (for an overview see Green & Bavelier, 2008).

There have been some reports of a positive transfer from cognitive-processing-speed training to driving behavior among older adults (Edwards et al., 2009; Roenker et al., 2003). In those studies, speed training was mainly administered on computer screens, focusing on the ability to identify visual information quickly in a central or divided-attention format. In the current study, we used physical exercise as the training strategy and emphasized not only stimulus perception but also adjusted and quicker motor responses.

Much research has focused on the effects of aerobic fitness on measures of cognitive function (ACSM, 1998); however, there has been a lack of studies concerning the hypothesis that physical activities exerting large cognitive demands may have an important influence on cognition (Spirduso, 2006). In addition, some meta-analysis did not support the cardiovascular-fitness hypothesis, which suggests that physical activity can enhance cognitive functioning only when aerobic fitness is improved (Colcombe & Kramer, 2003; Etnier et al., 2006). Thus, it is possible that mechanisms other than aerobic fitness may mediate changes in cognitive functioning obtainable through physical activity. Following this line of thought, special emphasis was given in the current study to the type of activities included in the exercise program. An important idea was to stimulate psychological mechanisms that promote transfer of learning from the exercise program to the driving tasks. The design of the exercise program was supported in the hypothesis that positive transfer of learning occurs primarily because of similarities between the amount and types of cognitive processes required by the performance situations (Magill, 2003).

Speed of behavior was successfully enhanced using a challenging form of exercise that simultaneously required physical effort (e.g., aerobic capacity and range of motion) and mental effort (e.g., speed of processing, visual attention, and
dual-task processing). Larger effect sizes were found in all tasks, with the exception of the peripheral RT task. The fact that marked improvements occurred in a sample of which about 50% were already engaged in exercise strengthens the idea that the perceptive and cognitive specificity of the program was fundamental. It is important to note that previous research has found that combined physical and cognitive training produced greater improvements in cognitive function than either physical or cognitive training alone (Fabre et al., 2002). Future studies should continue to examine this issue.

At follow-up, the composite score reflected better general speed of behavior. Improvement of information-processing speed is especially promising for its potential to affect older adults’ functional abilities that maintain independence and quality of life (Edwards et al., 2005; Owsley, Sloane, McGwin, & Ball, 2002). For instance, Ball et al. (2007) examined data from six studies that used the same computer-based processing-speed training program and concluded that participants maintained benefits of training for at least 2 years, which translated not only to safer driving performance but also to efficient performance of other instrumental activities of daily living. The relevance of the results from the current study also cosubstantiates the theory that changes in cognitive function with age can result from generalized, age-related slowing of processing speed (Birren & Fisher, 1995).

The current study has some limitations, and caution should be taken in generalizing the findings. A relatively small sample of drivers participated, and evaluations were conducted during open-road driving, but drivers were aware of the stimulus–response correspondence. In addition, possible bias might have been introduced in the study because the investigator involved in the assessments was not blinded to the participants’ group and because the control group did not receive any control intervention. Finally, it was not possible to differentiate between contributions to the obtained improvements by specific characteristics of the exercise program and possible training effects of physical fitness (physical fitness was not measured). Future research using longitudinal designs is needed to examine whether change in behavioral speed promoted by the exercise program can prevent motor-vehicle crashes among older drivers.

**Conclusion**

The current research showed that older drivers’ speed of behavior can be improved through exercise. Therefore, training interventions for older drivers should integrate exercise programs. Furthermore, the greatest functional benefits will be achieved if exercise programs for older adults incorporate activities that stimulate both perceptive and cognitive abilities.

**References**


