Speed-of-Processing and Driving Simulator Training Result in Improved Driving Performance

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Useful field of view, a measure of processing speed and spatial attention, can be improved with training. We evaluated the effects of this improvement on older adults' driving performance. Elderly adults participated in a speed-of-processing training program ($N = 48$), a traditional driver training program performed in a driving simulator ($N = 22$), or a low-risk reference group ($N = 25$). Before training, immediately after training or an equivalent time delay, and after an 18-month delay each participant was evaluated in a driving simulator and completed a 14-mile (22.5-km) open-road driving evaluation. Speed-of-processing training, but not simulator training, improved a specific measure of useful field of view (UFOV®), transferred to some simulator measures, and resulted in fewer dangerous maneuvers during the driving evaluation. The simulator-trained group improved on two driving performance measures: turning into the correct lane and proper signal use. Similar effects were not observed in the speed-of-processing training or low-risk reference groups. The persistence of these effects over an 18-month test interval was also evaluated. Actual or potential applications of this research include driver assessment and/or training programs and cognitive intervention programs for older adults.

INTRODUCTION

Some older drivers are prone to crashing, whereas others remain crash free throughout their driving careers. Until fairly recently, little has been known about which behavioral and physiological changes differentiate competent older drivers from those experiencing a decline in driving ability. However, numerous studies in the literature (e.g., Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Ball et al., 2002; Goode et al., 1998; Owsley et al., 1998; Owsley, Ball, Sloane, Roenker, & Bruni, 1991; Rizzo & Dingus, 1996; Rizzo, Reinach, McGehee, & Dawson, 1997) demonstrate that the driving performance of older drivers is related to a specific functional measure of visual processing speed, the useful field of view test (UFOV®). Furthermore, Ball and her colleagues (e.g., Ball, Ball, et al., 1988; Ball & Owsley, 1991; Edwards et al., 2002) have shown that the size of the useful field of view can be expanded with training. Therefore, the present investigation was designed to determine if speed-of-processing training also produces an improvement in driving performance. Given that 17% (55 million) of the population is expected to be over age 65 by the year 2020 (U.S. Department of Transportation, 1997), the development of techniques to help older adults maintain their mobility and lessen the risk of crash involvement has clear societal benefits.

The *useful field of view* has been defined as the area from which one can extract visual information in a single glance without eye or head movement (Sanders, 1970). It is measured binocularly and can involve the detection, localization, or identification of targets against more complex visual backgrounds (Verriest et al., 1983, 1985; Sanders, 1970). The size of the useful field of view is affected by many factors,

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including visual sensory function (Owsley, Ball, & Keeton, 1995), a slowing of processing ability, the inability to divide attention, and the inability to ignore distractors (Ball, Roenker, & Bruni, 1990). Measures of these last three factors have been incorporated into the UFOV® test administered on the Visual Attention Analyzer (see Ball et al., 1990). The UFOV® test measures the speed at which individuals can process information within a 30° radius visual field under a variety of cognitively demanding conditions.

As noted earlier, recent retrospective (Ball et al., 1993; Goode et al., 1998; Owsley et al., 1998; Owsley et al., 1991) and prospective studies (Ball et al., 2002; Owsley et al., 1998) have shown that older drivers with UFOV® impairments are involved in at-fault crashes more frequently than are drivers without these deficits. Other lines of evidence have supported this relationship. For example, Rizzo and colleagues (Rizzo & Dingus, 1996; Rizzo et al., 1997) have shown a similar relationship between UFOV® impairments and simulator crashes. In another simulator study, Chapparro and his colleagues (Chaparro, Alton, Sifrit, & Groff, 2001; Sifrit, Chaparro, Groff, & Stumpfhauser, 2001) have shown that individuals with UFOV® impairments encounter more difficulty in detecting peripheral targets and reacting to them in a driving simulator than do unimpaired individuals. Finally, Myers, Ball, Kalina, Roth, and Goode (2000) have shown that there is a linear relationship between the degree of UFOV® impairment and the probability of passing an on-the-road driving evaluation. Thus the relationship between UFOV® performance and driving performance has been well established, and interest has turned to ways to minimize impairments and thereby reduce the risk for crash involvement.

There is abundant evidence that older adults can benefit from perceptual and/or speeded task training (e.g., Kramer, Larish, & Strayer, 1995; Kramer, Larish, Weber, & Bardell, 1999) For example, Kramer and his colleagues have shown that after "variable priority practice," in which the relative attention applied to two tasks is varied in a nonsystematic fashion across practice sessions, older adults' performance on subsequent attention-switching tasks approaches that of younger participants. This ability to rapidly switch attention between multiple tasks clearly seems relevant for driving. Furthermore, the transfer of perceptual/cognitive training to simulated and actual driving performance is not unprecedented. Sifrit et al. (2001) found that a form of speed-of-processing training led to greater situational awareness (number of hazards detected) in a simulated driving task. Sivak et al. (1984) found that training individuals on a series of elementary perceptual tasks (visual scanning, figure-ground discrimination, etc.) led to improved open-road driving performance in a small sample of individuals with brain damage. Although it is unclear which aspect of the training was responsible for subsequent changes in driving behavior, their results demonstrate that training of fundamental perceptual/cognitive skills can improve driving performance.

In the process of exploring the factors that affected UFOV® test performance, Ball, Beard, Roenker, Miller, and Griggs (1988) developed a speed-of-processing training program that has been shown to expand the size of the useful field of view. The benefits of this training protocol have been shown to generalize to untrained stimuli over shorter stimulus durations (Ball, Ball, et al., 1988; Ball, Beard, Roenker, Miller, & Ball, 1988; Ball et al., 1991; Sekuler & Ball, 1986).

Thus there is clear evidence that certain types of training can produce cognitive changes that have the potential to improve driving performance. However, the detection of such benefits is problematic because of the difficulties encountered in trying to define and measure driving competence. There have been three major methods for assessing driving skills: crash history, driving simulator performance, and on-the-road driving performance. Each of these methods has advantages and disadvantages. Crashes are a relatively insensitive measure of driving performance because they are rare events and often go unreported by either the individual (Owsley et al., 1991) or the reporting agency (i.e., some states do not record crashes that occur on private property). Driving simulators offer experimental control over the driving experience, but they often lack high fidelity with actual driving and may result in simulator sickness, particularly for older adults. Road tests are frequently considered to be the best measure of driving competence, but they also have their drawbacks, particularly with respect to inconsistencies in the administration and scoring of the results. For example, road tests vary in traffic density (Herbert, 1963; Summala, Nieminen, & Punto, 1996), number of evaluators (Odenheimer et al., 1994; Sivak et al., 1984), sampling period (Hunt, Morris, Edwards, & Wilson, 1993; Sivak et al., 1984), and rating systems (Hunt et al., 1993).

The present study uses an on-the-road driving evaluation that attempts to minimize the methodological limitations often associated with this outcome measure. In particular, a complex rating system involving 455 operationally defined behaviors was developed. Second, multiple evaluators were used and their reliability was assessed. Finally, the route was repeated twice to provide an opportunity for a range of traffic conditions to occur. The present study attempts to detect changes in on-the-road driving behavior induced by a form of cognitive practice, speed-of-processing training.

METHOD

Participants

The participants were 456 licensed drivers (187 men, 269 women; 428 Caucasians, 28 African Americans) with an average age of 69 years (range 48–94 years) who were screened for participation in the training study. The participants were residents of Warren County, Kentucky, and the surrounding area and were recruited using a variety of methods (letters sent by the Kentucky Transportation Cabinet to crash-involved drivers age 55 and older, telephone calls, and talks to community groups).

In order to identify older drivers who would potentially benefit from speed-of-processing training, screening measures of visual acuity, contrast sensitivity, and UFOV® were conducted. Visual acuity (Lighthouse Distance Visual Acuity Test, second edition; Ferris, Kassoff, Bresnick, & Bailey, 1982) and contrast sensitivity (Pelli, Robson, & Wilkins, 1988) were assessed binocularly using the participant's corrective lenses. Inclusion criteria for the training study were a Bailey-Lovie acuity score (Bailey & Lovie, 1980) of .50 logMAR or better and a log contrast sensitivity of 1.35 or better (Bailey & Lovie, 1980); these values have been shown by Owsley et al. (1995) to be the minimal visual skills necessary to perform the UFOV® task. Participants who failed this visual screening (n = 2) were referred to a vision specialist and excluded from participation.

Study inclusion criteria also included UFOV® reduction. Inclusion in either the speed-of-processing or simulator training group required a minimum of 30% total reduction on the UFOV® measure. Prior research (Ball et al., 1993; Owsley et al., 1991) has shown that a cut point of 40% reduction provides maximum sensitivity and specificity in predicting crash involvement from state records. Crash involvement, however, is a relatively insensitive measure of driving performance, and given that the primary measure of driving performance in the present investigation was on-the-road driving, a more lenient cut point (30% reduction) was selected.

The goal of recruitment into the training study was to include a minimum of 50 individuals exhibiting UFOV® decline in the "high-risk" speed-of-processing training group (the training of interest), 25 individuals exhibiting similar decline in a driving simulator training control group (traditional driver training), and 25 individuals who did not exhibit UFOV decline in a "low-risk" reference group. Although our prior research has clearly shown that speed-of-processing training results in a robust increase in the size of the useful field of view, we were concerned that the transfer of any such benefits to a skill such as driving might be difficult to detect. Hence we doubled the sample size for the speed-of-processing training group, which resulted in sufficient power (e.g., .80) to detect effect sizes as small as .35. Additionally, our primary interest was in assessing any such benefits relative to a sham training control group. The traditional driver training program employed in the current research utilized a noninteractive driving simulator, and we expected that any benefits derived from such training would be both minimal and short lived, given that our participants were experienced drivers. Finally, the low-risk reference group was included to serve as a second control group against which the baseline driving performance of the two high-risk groups could be compared.

The degree of UFOV® decline was assessed on the Visual Attention Analyzer. Before UFOV® testing began, all participants demonstrated the necessary sensory capacity to correctly locate at least 75% of the peripheral targets.

Training Participants

In the training study were 104 participants (38 men, 66 women; 100 Caucasians, 4 African Americans) with a mean age of 71 years (range 55–86). Of the 456 individuals screened, 3 failed to complete the protocol and 2 were excluded for visual impairment. From the 276 participants who had a UFOV® reduction of less than 30% (i.e., UFOV® intact), 27 were randomly selected for the low-risk reference group. Of the 175 participants with a UFOV® reduction of 30% or greater, 34 declined to participate, and 77 of the remaining 141 were selected for participation so as to create a range of UFOV® performance. Within this group, 26 were assigned to the simulator training control group and 51 were assigned to speed-of-processing training. Assignment was random with the constraint that 2 participants were assigned to the speed-of-processing training group for every participant assigned to the simulator training group. All participants were paid for their participation.

Procedure

Driving simulator measures. Participants' simple (SRT) and choice reaction time (CRT) were assessed in a driving simulator (Model L-225, Doron Precision Systems, Inc., Binghamton, NY) consisting of a 35-mm projection system and five driving consoles (steering wheel, brake and accelerator pedals, and an instrumented dashboard).

For SRT, the participant was instructed to watch a light arrangement containing six colored lights (1 × 1 cm) located on the top panel of the driver's unit. Color-matched pairs of these lights blinked on for 1 s (and off for 0.5 s) in a random order. The driver was instructed to brake as quickly as possible when the two red lights (simulated brake lights) were illuminated. After at least 3 practice trials, 15 experimental trials were performed. The datum for each trial was the elapsed time between the onset of the brake lights and the release of the accelerator pedal.

For CRT, a narrated film from the Doron film library was viewed at a distance of 5.8 meters. The stimuli (44 × 46 cm, or 4.3° × 4.5°) were road signs (pedestrian, bicycle, right and left turn arrows) with and without a red slash through them. Participants were instructed to react only to signs without a red slash, by braking for bicycle or pedestrian signs or by turning the steering wheel in the appropriate direction for right or left turn arrows. A value of 3.1 s was assigned for trials in which the action signal was not detected because this was the length of time the display remained visible. The number of stimuli ranged from three to six signs, and within a trial this number was held constant, although the positions of the signs changed throughout the frames. Two identical sets of 10 trials were completed.

On-the-road driving evaluation. The driving evaluation course was designed based on a review of the accident literature, traditional driver's tests, and fitness-to-drive evaluations. The course consisted of two loops of a 7-mile (~11.3-km) urban/suburban route. To aid raters in completing their evaluations, maps in the rater's manuals included landmarks at each intersection that were used to define the start and end points for evaluating specific driving behaviors. Finally, an analysis of the older driver literature (e.g., Odenheimer et al., 1994) indicated that certain maneuvers, such as left turns across traffic, are especially difficult for older drivers. These locations in the drive were thus considered to constitute places of potential danger. For each of these locations, an item was included to code the extent to which the driver's behavior constituted a dangerous maneuver. A dangerous maneuver was defined as one in which either the driving instructor had to take control of the car or other vehicles had to alter their courses in order to avoid a collision.

The raters' evaluation manual contained a total of 455 items. In order to minimize the demands of the evaluator's task, the three raters practiced evaluating drivers on each course segment until all scoring criteria could consistently be applied by all raters. This training was effective, as evidenced by the high ($r \geq .92$) interrater reliability achieved during the road test evaluation (see Results section). The evaluators were required to note only inappropriate driving behaviors. A pilot study was performed on the road test using 4 elderly volunteers to ensure that the course was not too difficult.

The open-road driving evaluation was performed in a car modified with a passenger-side brake for the driving instructor's use. Before beginning the evaluation, the driver was familiarized with the car. The driving instructor informed the driver that he would provide route instructions and that the driver should operate the car as he or she normally would. The driving instructor followed a script in order to give standardized directions. The driver was then directed through a 1-mile (~1.6-km) warm-up route. The subsequent driving evaluation consisted of two loops of a 7-mile (~11.3-km) urban/suburban course. The evaluation was performed during the day (between 7:30 a.m. and 5:00 p.m.) and required 50 to 60 min to complete.

Two of the three independent backseat evaluators rated each driver. All possible combinations of the three evaluators were used. For the pretraining drive, the driving instructor and backseat evaluators were blind to the training condition assigned for all participants. On the posttraining drive, the driving instructor was blind to whether participants were in the speed-of-processing training group or the low-risk reference group. In addition, for approximately half of the drives, one of the backseat evaluators was blind to the condition to which the participant had been assigned. By comparing the responses of each pair of evaluators, it was possible to guard against any potential bias during the driving evaluation. An analysis of interrater reliability showed that the reliability was equally high when both evaluators were blind (r = .92), one evaluator was blind (r = .95), or neither evaluator was blind (r = .92) to the drivers' training condition.

All driving behaviors except one were rated on a 0 (*very unsafe*) to 2 (*safe or appropriate*) scale. Scale ratings were operationalized for each behavior at each location on the course. Behaviors included maintaining lane position, activating signals, stopping smoothly, searching (additional mirrors were placed in the car to aid the raters in detecting eye movement), selecting gaps, accelerating and decelerating smoothly, turning, maintaining speed, maintaining position in traffic, and dangerous maneuvers. The one behavior rated on a 4-point (from –1 to 2) scale was stopping at stop signs, with –1 defined as running the stop, 0 as rolling through the stop, 1 as inappropriate stop position, and 2 as an appropriate stop.

After the drive, the raters also provided a global rating of the drive (minimum interrater reliability = .94). This global rating ranged from 1 (*drive aborted/very unsafe*) to 6 (*very competent driver*).

Training. The low-risk reference participants did not receive any training but participated in the same pre- and posttest assessment sessions as did the two high-risk groups. These assessments were separated by an equivalent amount of time (2 weeks) as those of the training groups. As previously described, participants selected for the low-risk reference group were individuals without UFOV® impairment. This group provided age-matched baseline performance against which we could evaluate the performance of the training groups.

Speed-of-processing training was evaluated relative to a simulator-based training program designed to control for social contact and instructional aspects of training. The simulator training program was representative of a current method of driver retraining and focused on teaching specific driving behaviors. Alternatively, in the speed-of-processing training program, participants did not practice any specific behaviors related to on-the-road vehicle operation; instead, they practiced a fundamental processing skill.

Simulator training control group. A certified driving instructor conducted two educational sessions with groups of 3 to 4 participants each. The first 2-hr session consisted of a review of the general rules of the road and instruction about and simulated practice of safe driving and crash prevention behaviors. Each trainee individually practiced with Doron driving simulator films demonstrating techniques for crash avoidance, managing intersections, and scanning. Simulator instruction provided participants with skills that were directly applicable to the road test and thus had high face validity for the participants. The second 2-hr session continued with the simulation instruction and ended with a 1-hr in-car demonstration by the driving instructor of many of the described skills.

Speed-of-processing training. Speed-of-processing training, administered on a touch-screen computer, was individualized. A detailed description of training protocols has been provided elsewhere (e.g., Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball et al., 1991; Edwards et al., 2002), and only a brief summary is provided here. Based on an initial UFOV® screening, the threshold for the first UFOV® subtest (stimulus identification) was determined. If this threshold was greater than 30 ms, training was implemented by having participants practice the task at progressively faster presentation speeds until the participant's threshold was lowered to 17 ms.

The second level of training required the participant to perform the centrally located identification task and also to locate a peripheral target presented at up to 30° of eccentricity. If the participant was unable to perform these two tasks at the shortest exposure duration (40 ms), he or she was further trained, first by practicing the identification task in conjunction with locating peripheral targets near the central fixation box (i.e., 10° of eccentricity) at a presentation duration slightly faster than threshold. As this task was mastered, the targets were moved farther into the periphery (e.g., 20°, 30°). When the participant could correctly locate the peripheral target at 30° eccentricity with approximately 75% accuracy, the process was repeated with near targets (e.g., 10°) and a presentation duration 40 ms faster than the previous training speed. This entire process was repeated at progressively faster presentation speeds until the participant could perform both the identification task and the peripheral localization task (at 30°) with approximately 75% accuracy at the fastest presentation speed (40 ms).

The third level of training required the participant to perform the identification task and locate the peripheral target embedded among distractors. If the participant was unable to perform these two tasks at an exposure duration of 120 ms, training was provided in the same manner as described earlier. Practice continued until 75% correct performance was achieved at an exposure duration of 120 ms with peripheral targets at 30°. Thus all participants were trained to criteria. The average number of training trials completed was 1040 (SD = 504, range 368–3104). The average training time was 4.5 hr. Unlike the simulator training, the speed-of-processing training had little face validity for the participants, who routinely questioned the relationship of such training to driving performance.

Posttraining assessment. Posttraining measures were obtained once again in the driving simulator, on the road, and on UFOV®. For all groups a 2-week period, on average, elapsed between the pre- and posttraining assessments. Following the posttraining driving evaluation, the participants were offered an individual road test report prepared by the driving instructor. Participants were invited to return for follow-up testing 18 (±1) months after the posttraining evaluation, and 60 did return (speed of processing n = 28, simulator n = 14, low-risk reference n = 18). The 18-month assessment procedure was identical to the pre- and posttraining assessment procedures. A comparison of those who chose to return and those who did not revealed no baseline differences in age, speed-of-processing impairment, reaction time, or performance on any of the driving composites.

RESULTS

Of the 26 participants in the simulator training group, 22 (mean age = 72.35 years, SD = 5.36, range = 63–81) completed the baseline and immediate posttest protocol (3 dropped out because of simulator sickness and 1 because of equipment failure) and 14 returned for the 18-month follow-up. Of the 51 participants in the speed-of-processing training group, 48 (mean age = 72.08 years, SD = 6.82, range = 59–86) completed the training protocol (2 dropped out because of illness and 1 had discontinued driving) and 28 returned for the 18-month follow-up. Of the 27 participants in the reference group, 25 (mean age = 69 years, SD = 6.85, range = 55–80) completed both baseline and immediate posttesting (2 chose to discontinue participation), with 18 returning for follow-up testing. Missing values for the 18-month follow-up (approximately 13%) were imputed by inserting, for that individual, the mean immediate posttest value for the respective group for that variable.

In all analyses, gender was initially included as a variable. However, in all cases there was neither a main effect for gender nor any interactions involving gender. Thus subsequent analyses were collapsed across gender.

Analysis Plan

For each of the outcome variables (UFOV®, SRT, CRT, and driving performance) a 3 (groups) × 3 (time) mixed analysis of variance was performed. In addition, in cases where the Group × Time interaction was significant, simple effects analyses and planned comparisons were employed to examine differences between groups at each measurement point. Additionally, Bonferroni's test (.05) was used to examine changes within groups over time. Recall that the design included a low-risk, unimpaired reference group whose purpose was to serve as a reference point against which to evaluate relative changes in the two impaired groups of interest. Therefore, the guiding principle in the simple effects analyses was to compare the performance of the two high-risk training groups with that of the low-risk reference group.

Before proceeding to these analyses it was necessary to reduce the abundant data from the driving evaluation into a more manageable form. Given the high interrater reliability (.93, *SD* = .05; .94, *SD* = .05; and .92, *SD* = .05 for the pretraining, posttraining, and 18-month follow-up drives, respectively) and the large number of behaviors rated, the 455 items were grouped into 13 composites based on the behaviors being rated. For example, all items that required the evaluator to determine the vehicle's position relative to other traffic were grouped together into a single composite, regardless of where these ratings were made during the course of the drive.

The resulting 13 composites were (a) acceleration: smoothness in use of the accelerator pedal; (b) gap selection: safely merging into or crossing traffic flow; (c) position in traffic: position relative to surrounding traffic while moving; (d) search: eye and head movements at intersections; (e) signals: proper and timely use of turn signals; (f) speed: vehicle speed control relative to posted speed limits; (g) stop position: vehicle position when required to stop at a traffic control device; (h) deceleration: smoothness in vehicle deceleration; (i) tracking: position of vehicle in proper lane; (j) turning: position of vehicle when turning; (k) right of way: yielding to traffic at four-way stops; (l) changing lanes: changing lanes on a multiple-lane road; and (m) dangerous maneuvers: the degree of danger felt by the raters at 17 potentially dangerous locations during the road test. These 17 locations involved high-traffic roadways and were composed of 6 unprotected left turns across traffic, 9 left turn entrances to a high-traffic road, and 2 opportunities for inappropriate stopping in traffic to make a right turn.

Unfortunately we were forced to drop five of the composites from the analysis. Performance on four of the composites (gap selection, acceleration, deceleration, and right of way) suffered from ceiling effects. Performance was perfect on approximately 97.5% of the observation opportunities, and mean performance never dropped below 1.94 on a 2-point scale. The search composite was dropped for lack of sufficient data. Although additional mirrors were placed in the vehicle to aid in the detection of eye movements, certain situations (e.g., driver wearing sunglasses, movement of the sun visor) made this assessment difficult. These events frequently took place in middrive, making subsequent evaluation impossible.

For each of the remaining eight composites, scores were generated by averaging both raters' scores (0 = *unsafe*, 1 = *somewhat unsafe*, 2 = *safe*) on all of the items making up that composite. However, the dangerous maneuvers composite was transformed into the actual number of dangerous maneuvers for ease of presentation.

UFOV® test. Means and standard deviations for UFOV®, SRT, and CRT at each of the three testing points are presented in Table 1. An analysis of the UFOV® data (see Figure 1) revealed significant effects for group, $F(2, 92) = 19.32$, $p < .001$, $MSE = 118.97$, $\text{eta}^2 = .30$; time, $F(2, 184) = 54.59$, $p < .001$, $MSE = 37.74$, $\text{eta}^2 = .37$; and a Group × Time interaction, $F(2, 184) = 40.17$, $p < .001$, $MSE = 37.74$, $\text{eta}^2 = .47$. Simple effects analysis of the data revealed that at baseline, as assigned, the low-risk reference group

TABLE 1: UFOV®, SRT, and CRT Measures: Mean (*SD*) Baseline, Immediate Posttraining, and 18-Month Posttraining Scores

	Reference, *n* = 25			Simulator, *n* = 22			SOP[a], *n* = 48		
	Base	Post	18 Mo	Base	Post	18 Mo	Base	Post	18 Mo
UFOV®	23.40	22.88	25.10	37.95	33.41	34.23	41.41	16.93	27.11
	(4.73)	(7.08)	(8.63)	(11.79)	(10.62)	(10.17)	(9.74)	(4.87)	(5.31)
Simple RT (s)	0.865	0.861	0.873	0.916	0.891	0.952	0.895	0.891	0.901
	(0.160)	(0.163)	(0.161)	(0.305)	(0.179)	(0.227)	(0.162)	(0.175)	(0.165)
Choice RT (s)	1.829	1.752	1.750	2.049	1.983	1.874	2.176	1.899	1.979
	(0.223)	(0.239)	(0.223)	(0.310)	(0.241)	(0.243)	(0.321)	(0.310)	(0.302)

a SOP = speed of processing.

had significantly smaller UFOV® reduction than did the two training groups. At immediate posttest, however, the speed-of-processing-trained group's performance was equal to that of the low-risk reference group, whereas the simulator-trained group's performance remained high. This pattern was still present at the 18-month follow-up. Thus the speed-of-processing training was effective in decreasing the degree of useful field of view reduction, and this training effect persisted at the 18-month follow-up.

SRT. For the simple RT measure there were no effects of group or time, nor was there an interaction (all Fs < 1.99, ps > .05), indicating that this measure was insensitive to group differences or training effects.

CRT. The choice RT data are presented in the top panel of Figure 2. An analysis of these data revealed significant effects for groups, $F(2, 92) = 6.02$, $p < .003$, $MSE = 0.189$, $\text{eta}^2 = .12$; time, $F(2, 184) = 34.23$, $p < .001$, $MSE = 0.025$, $\text{eta}^2 = .27$; and a Group × Time interaction, $F(2, 184) = 4.35$, $p < .002$, $MSE = 0.025$, $\text{eta}^2 = .09$. Simple effects revealed that the low-risk reference group had, as expected, faster CRT at each of the three testing points. Post hoc analyses revealed that the simulator-trained group's CRT remained relatively stable over time, whereas the speed-of-processing-trained group showed an initial drop at immediate posttest, which was maintained at the 18-month follow-up.

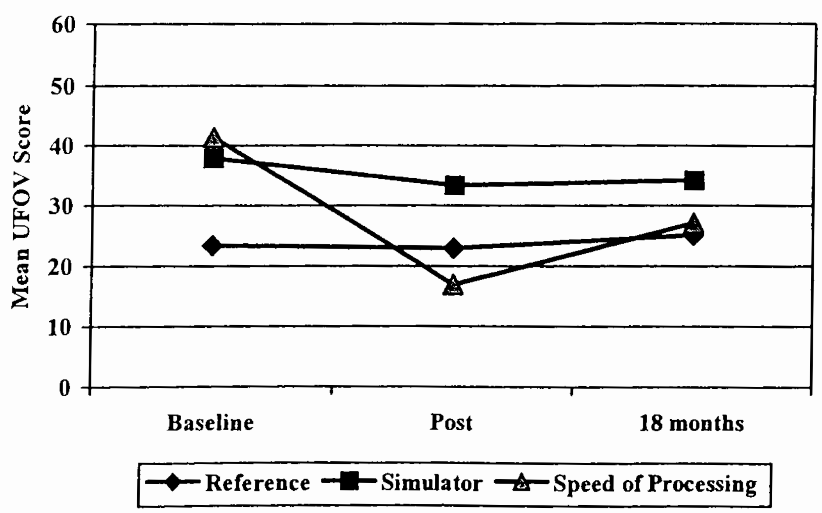

Figure 1. Useful field of view performance across time by group.

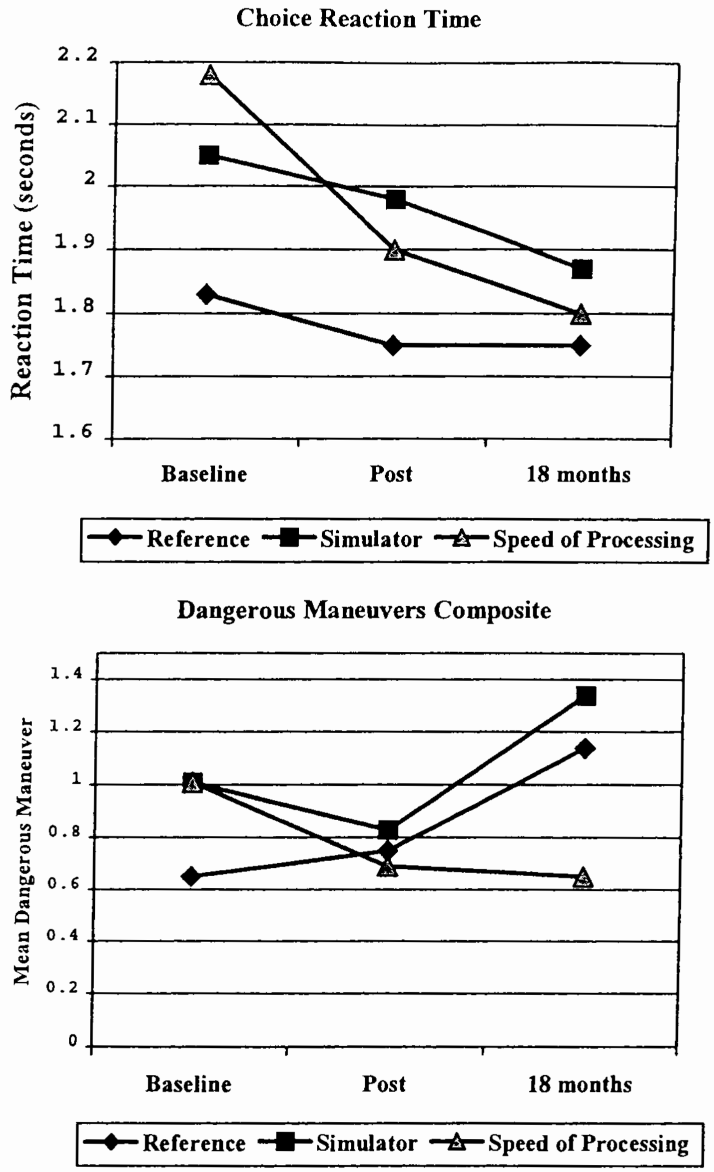

Figure 2. Choice reaction time performance and dangerous maneuvers across time by group.

On-the-Road Driving Evaluation

Global rating. Means and standard deviations for the eight driving composites and the global driving rating are presented in Table 2. There was an overall improvement in global rating across testing sessions, $F(2, 184) = 9.85$, $p < .001$, $MSE = 0.32$, $\text{eta}^2 = .10$, and a Group × Time interaction, $F(4, 184) = 3.26$, $p = .013$, $MSE = 0.32$, $\text{eta}^2 = .07$. Simple effects analyses revealed that at baseline, as expected, the low-risk reference group's global rating was higher than that of the simulator and speed-of-processing groups. These differences had disappeared at the immediate posttest. However, at the 18-month follow-up the simulator-trained group's global rating was significantly lower than that of the low-risk reference group. Post hoc tests revealed that ratings for the low-risk reference group remained high and did not

TABLE 2: Global Rating and Driving Evaluation Composites: Mean (*SD*) Baseline, Immediate Posttraining, and 18-Month Posttraining Scores

	Reference, *n* = 25			Simulator, *n* = 22			SOP[a], *n* = 48		
	Base	Post	18 Mo	Base	Post	18 Mo	Base	Post	18 Mo
Global rating[b]	4.41 (1.26)	4.54 (1.16)	4.68 (1.20)	3.61 (1.45)	4.30 (1.53)	3.63 (1.55)	4.04 (1.18)	4.39 (1.19)	4.25 (1.22)
Driving Composites[c]									
Dangerous maneuvers[d]	0.65 (1.15)	0.75 (1.00)	1.14 (1.73)	1.01 (0.78)	0.83 (1.04)	1.34 (1.45)	1.01 (1.26)	0.69 (0.96)	0.65 (0.88)
Signals	1.83 (0.16)	1.75 (0.26)	1.84 (0.20)	1.74 (0.28)	1.84 (0.18)	1.77 (0.26)	1.74 (0.26)	1.76 (0.26)	1.78 (0.27)
Turning	1.51 (0.17)	1.56 (0.18)	1.57 (0.20)	1.39 (0.25)	1.57 (0.28)	1.53 (0.28)	1.43 (0.24)	1.46 (0.24)	1.55 (0.20)
Changing lanes	1.94 (0.22)	1.80 (0.56)	1.97 (0.42)	1.89 (0.44)	1.89 (0.44)	1.68 (0.58)	1.97 (0.12)	1.94 (0.20)	1.92 (0.23)
Position in traffic	1.87 (0.26)	1.96 (0.16)	2.00 (0.00)	1.88 (0.25)	1.98 (0.11)	1.98 (0.07)	1.91 (0.23)	1.99 (0.05)	1.88 (0.18)
Stop position	1.92 (0.10)	1.91 (0.10)	1.94 (0.08)	1.85 (0.15)	1.90 (0.12)	1.86 (0.16)	1.90 (0.08)	1.92 (0.09)	1.90 (0.08)
Tracking	1.94 (0.07)	1.96 (0.05)	1.95 (0.08)	1.88 (0.18)	1.91 (0.18)	1.85 (0.19)	1.91 (0.09)	1.92 (0.09)	1.91 (0.11)
Speed	1.89 (0.18)	1.88 (0.15)	1.91 (0.13)	1.86 (0.15)	1.81 (0.25)	1.80 (0.24)	1.85 (0.19)	1.88 (0.16)	1.88 (0.14)

[a] SOP = speed of processing. [b] Global rating: Scores are averaged across two raters who rate on a 1–6 scale in which 1 = *aborted drive* and 6 = *competent driver*. [c] Driving composites: Composite scores are averaged across two raters on all of the items within the composite. Scores for all but the driving maneuvers composite range from 0 to 2 (0 = *unsafe*, 1 = *somewhat unsafe*, 2 = *safe*). [d] The dangerous maneuvers composite is the mean number of dangerous maneuvers observed; thus lower scores reflect better performance.

change across testing sessions, whereas the simulator-trained group was rated poorer at baseline, approached the reference group's overall level of performance at the immediate posttest, and returned to baseline levels at the 18-month follow-up. There was a general, but not significant, increase in global ratings of the speed-of-processing group over time.

Driving composites. The eight driving composites provided an opportunity to determine more precisely the nature of changes in driving performance over time. Five of the eight composites yielded significant Group × Time interactions. These effects are examined in the following paragraphs.

For the dangerous maneuvers interaction, $F(4, 184) = 2.89$, $p < .024$, $MSE = 0.667$, $\text{eta}^2 = .06$. The data for the dangerous maneuvers composite is presented in the bottom panel of Figure 2. As expected, the low-risk reference group had fewer dangerous maneuvers during the baseline drive than did either of the high-risk training groups. At immediate posttest, the number of dangerous maneuvers for both training groups dropped and was not significantly different from that of the low-risk reference group. However, at the 18-month follow-up, both the low-risk reference and the simulator-trained groups demonstrated significantly more dangerous maneuvers than did the speed-of-processing-trained group.

For the signals interaction, $F(4, 184) = 7.22$, $p < .001$, $MSE = 0.008$, $\text{eta}^2 = .14$. The top panel of Figure 3 presents the signal composite data. Simple effects analyses revealed that the low-risk reference group was more consistent in their use of turn signals at baseline than were the two training groups. However, at immediate posttest the low-risk reference group's use of turn signals declined, whereas that of the simulator-trained group improved. This latter effect is not surprising, given that some of the simulator training was directly devoted to proper signaling. These changes did not persist; both groups returned to baseline levels at 18 months. At each assessment from

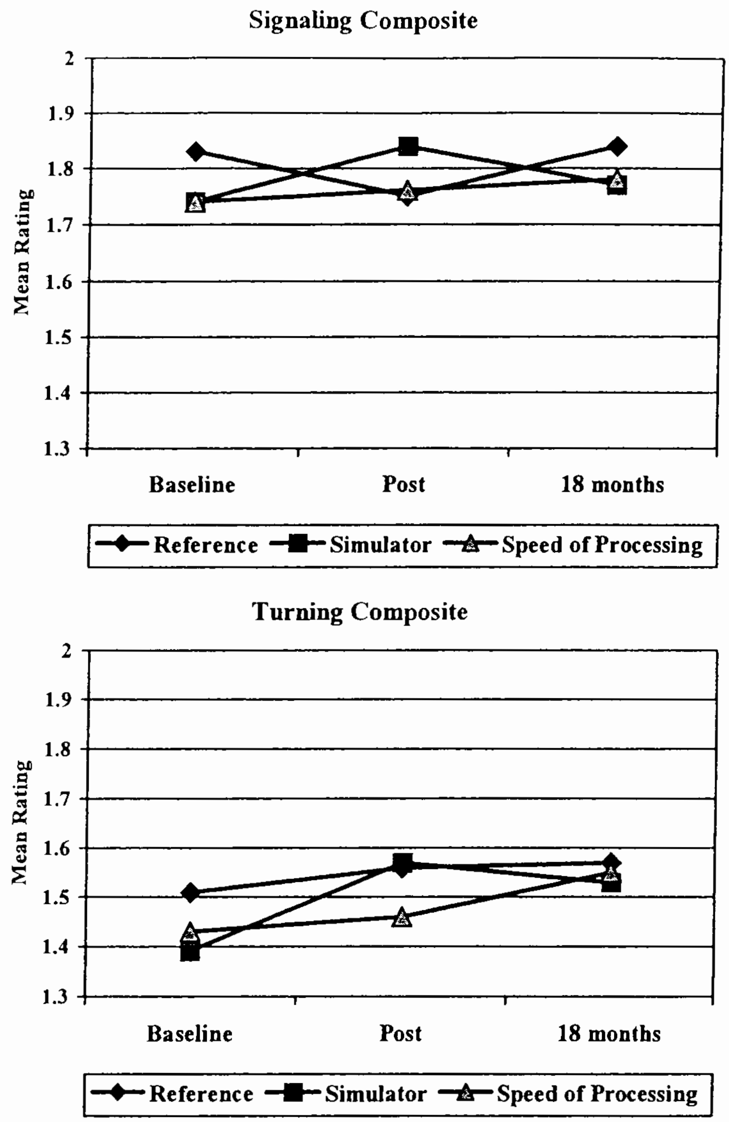

Figure 3. Signaling and turning composites across time by group.

baseline to 18 months, the speed-of-processing-trained group maintained the same level of signal use.

For the turning interaction, $F(4, 184) = 4.30$, $p < .002$, $MSE = 0.012$, $\text{eta}^2 = .09$. The turning composite data are presented in the bottom panel of Figure 3. The low-risk reference group was better than either of the two high-risk groups at turning into the proper lane at baseline. The simulator-trained group showed improvement at immediate posttest, whereas the speed-of-processing group did not, relative to the low-risk reference group. Again, because proper turning was a focal point of the simulator training protocol, this effect is not surprising. The three groups did not differ at the 18-month follow-up.

For the changing lanes interaction, $F(4, 184) = 2.92$, $p < .023$, $MSE = 0.073$, $\text{eta}^2 = .06$. The three groups did not differ at baseline on the ability to correctly change lanes in traffic. However, at immediate posttest there was a decline in performance by the low-risk reference group relative to the two training groups. At the 18-month follow-up, the low-risk reference group had returned to baseline levels, and the simulator-trained group's performance was significantly lower than that of either the low-risk reference or the speed-of-processing-trained group. This pattern of changes was unexpected. Post hoc analyses showed that the speed-of-processing group's performance remained constant over the three assessments.

For the position in traffic interaction, $F(4, 184) = 2.71$, $p < .032$, $MSE = 0.115$, $\text{eta}^2 = .06$. The three groups were equivalent at baseline and at immediate posttest in maintaining the proper distance between vehicles in traffic, although there was a general improvement in all groups' performance over the first two test intervals, $F(1, 182) = 13.38$, $p < .01$, $MSE = 0.115$, $\text{eta}^2 = .05$. Simple effects revealed that at the 18-month follow-up, the speed-of-processing-trained group was significantly inferior to both the low-risk reference and simulator-trained groups. Thus the improvement noted for the immediate posttest was maintained at the 18-month evaluation point for the low-risk reference and simulator groups but not for the speed-of-processing group.

Collectively, these data present a picture of driving improvements specific to the type of training received. On one hand, simulator training resulted in an improvement in the behaviors expressly practiced during training (turning and signal usage). Most of these effects were temporary (dissipating by the 18-month follow-up). On the other hand, speed-of-processing training resulted in fewer dangerous maneuvers during the drive and a faster reaction time in a complex visual task. Both measures require rapid processing of complex visual information, which is targeted for improvement in speed-of-processing training. These effects persisted at the 18-month follow-up. Finally, the changes observed in the low-risk reference group over time may represent a return to more normal driving behavior as the drivers adjusted to the presence of the evaluators – a phenomenon that probably occurred across all groups but was counteracted in the training groups by the specific effects of training. Taken together, these data demonstrate divergent validity for the two types of training investigated.

DISCUSSION

The data from the present study demonstrate that both speed-of-processing training and driving simulator training can enhance the driving performance of at-risk older adults but that some of these gains may disappear over time in the absence of any form of "booster" training. Before discussing these results in detail, it is important to examine the methodological improvements of the present study as a context in which to then evaluate the current findings.

In designing this on-the-road driving study, an attempt was made to include the strengths and remove the weaknesses of previous driving studies (de Gier, 'r Hart, Nelemans, & Bergman, 1981; Hunt et al., 1993; Odenheimer et al., 1994; Sivak et al., 1984). First, in order to get the most realistic measure of driving skills and habits, each participant drove a 7-mile (~11.3-km) route twice. In repeating the route, the driver was allowed to become more comfortable with the evaluation process and therefore was more likely to revert to everyday behavior. Second, instead of using a limited 2-point pass/fail scale to rate behavior, we used a 3-point scale (*very unsafe, somewhat unsafe, safe*), which allowed for finer gradations in judgment corresponding to the wider range of real-world driving behaviors. Third, the driving behaviors were evaluated by two raters rather than a single individual (e.g., de Gier et al., 1981; Hunt et al., 1993). Very high interrater reliabilities (.93+), relative to those found by others (e.g., .74–.84, Odenheimer et al., 1994), were achieved. Whenever possible, at least one of the raters was blind to the treatment condition of the participant. Ratings by blinded and unblind evaluators were highly correlated, indicating an objective analysis of driving behavior.

Fourth, a large number of behavioral ratings (455) were obtained in the current study, as compared with previous studies (de Gier et al., 1981; Hunt et al., 1993; Odenheimer et al., 1994), again entailing a fuller range of driving behaviors than generally has been assessed in prior research. These item ratings were grouped into robust and stable composites, each of which was made up of numerous samples of driving behavior rather than a single instance. Finally, the evaluations were not limited to certain times of the day or to low-traffic conditions, and hence they encompassed a wide range of driving conditions. All these steps were undertaken in order to get the most accurate and least biased measures of driving skills as possible. Clearly, on-the-road driving studies inherently lack control over many circumstances, especially traffic conditions and the behavior of other drivers.

Finally, it is interesting to note that despite our best efforts to measure driving behavior under demanding situations, the performance of the participants in some areas was nearly perfect. Apparently the older adults in our sample, even those in the high-risk groups, had little difficulty waiting for an appropriate opening in traffic (gap selection), waiting for their turn at stop signs (yielding the right of away), or smoothly accelerating and decelerating an unfamiliar vehicle. These findings may not be surprising in light of the fact that these tasks are not ones that require rapid decision making or rapid processing of quickly changing information. In fact, most of our participants, even the high-risk ones, drove extremely cautiously, requiring an average of 1 hr to drive 14 miles (22.5 km). As further evidence of this cautiousness, performance on most of the other driving composites was quite high as well. Fortunately, driving failures (e.g., crashes or dangerous maneuvers) are relatively infrequent events, and weaknesses in driving skills may be evident only when the driver is placed in challenging situations that require them to rapidly evaluate and respond. These are precisely the kind of situations that older drivers report avoiding (Odenheimer et al., 1994).

In light of this study's improvements in assessing driving skills, as well as the limitations imposed by the driving environment, we now turn to consideration of the driving results. Although both the speed-of-processing and simulator groups were judged by the independent raters to have improved their driving skills, the nature of improvement for the two types of training varied. The simulator group did not improve on speeded reactions but did improve on a few of the specific driving maneuver skills on which they were trained (turning into the correct lane and signaling), whereas the speed-of-processing and the low-risk reference groups did not. Numerous participants indicated during simulator training that they intended to implement the skills being instructed. The data show, at least in these areas, that they were successful in doing so, although these newly acquired skills had largely disappeared by the time of the 18-month follow-up.

However, the speed-of-processing-trained group improved on untrained tasks that relied on visual attention and higher-order processing speed. The speed-of-processing-trained group improved on the choice reaction time task in the driving simulator, which involved scanning a visual scene, detecting changes in stimuli, and quickly reacting to those changes. For a vehicle moving at 55 miles/hr (88.5 km/hr), this improvement of 277 ms translates into a stopping distance 22 feet (6.7 m) shorter. The speed-of-processing-trained group also made fewer dangerous maneuvers during the posttraining drives than on the baseline drive. The dangerous maneuvers composite consisted of items that primarily tapped visual detection and judgment abilities in visually cluttered and cognitively demanding high-risk driving situations, such as scanning intersections for traffic control devices and making gap selections in order to make turns across oncoming traffic. These same behaviors (or rather the lack of them) are often cited as causes of crashes (Campbell, 1966; Kline, 1986).

Many participants in this training group questioned the link between the training they received and actual driving, and thus they did not expect to improve their driving skills. Taken together, these data indicate that the benefits of training were localized to logically compatible behaviors and that these effects were present over and above any general training effects. The benefits of speed-of-processing training, for the most part, were still present 18 months after training. Furthermore, it is important to note that many, but not all, of the individuals retained the benefits of speed-of-processing training, suggesting that a system of "booster" training may be necessary for some individuals.

These results expand on those of Sivak et al. (1984), who measured eight categories of behavior (gap acceptance, limit line, observations-turning, observations-straight, path-turning, path-straight, speed-turning, speed-straight). Using a composite of these measures, they reported an improvement in driving skills after perceptual training. Only composite results were reported, so it is not clear whether participants improved in all categories of behavior or in selected behaviors. The present study measured similar behaviors (gap selection, stop position, right of way, searching, turning, tracking, speed, and acceleration) as well as other behaviors (signals, position in traffic, changing lanes, deceleration) but analyzed for changes within each category of behavior. These analyses did not reveal categorical changes for the speed-of-processing-trained group, but an improvement was noted for the dangerous maneuvers composite, which included behaviors similar to those measured by Sivak et al. Thus our results, like those of Sivak et al., support the argument that functional benefits are derived from improving the speed with which one processes complex visual information, given that perceptual skills underlie many daily activities (e.g., driving, walking, general mobility in the environment). These findings are also consistent with the conclusion of Odenheimer et al. (1994) that selective attention skills are related to safe and successful negotiation of demanding traffic situations.

Over the last several years Fisk, Rogers, and their colleagues (e.g., Fisk & Rogers, 2000; Jamison & Rogers, 2000; Mead & Fisk, 1998; Rogers, Campbell, & Pak, 2001; Rogers, Fisk, Mead, Walker, & Cabrera, 1996) and others (e.g., Charness, Schuman, & Boritz, 1992; Czaja, 1996) have systematically investigated the acquisition and retention of new technology skills by older adults. This work has been motivated largely by an attempt to understand how training methodology should be altered in light of the known changes in cognition that accompany aging.

The current research speaks to several points raised in this literature. First, as Rogers et al. (1996) have pointed out, for older adults interactive training is more effective than other forms of training. In the current research, although both the speed-of-processing and simulator training involved interactive training, the interactive nature of the training was far more extensive in the speed-of-processing than in the simulator training. This may explain, in part, why the effects of simulator training had largely dissipated by 18 months. Second, as Fisk and Rogers (2000) have noted, older adults, despite declines in cognitive ability that accompany aging, show little if any decline in the performance of many well-learned skills. This is consistent with the findings of the current research, in that many of the driving skills of the older adults were performed at near-perfect levels. However, as Walker, Fain, Fisk, and McGuire (1997) have noted, older adults are slower to make driving decisions (e.g., route selection) than are younger adults, but if they are given sufficient time the quality of their decisions does not decline. It is precisely these decision points, which occur unexpectedly during the drive and require a rapid response, that have been associated with increased crash risk in older adults (e.g., Campbell, 1966; Kline, 1986) and for which the impact of speed-of-processing training can be seen.

In summary, these data add further weight to the accumulating research linking processing speed deficits to driving performance failures by older adults. Furthermore, the current data suggest that these processing deficits can be ameliorated through speed-of-processing training and that this improvement results in safer driving behaviors that are durable for at least 18 months.

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