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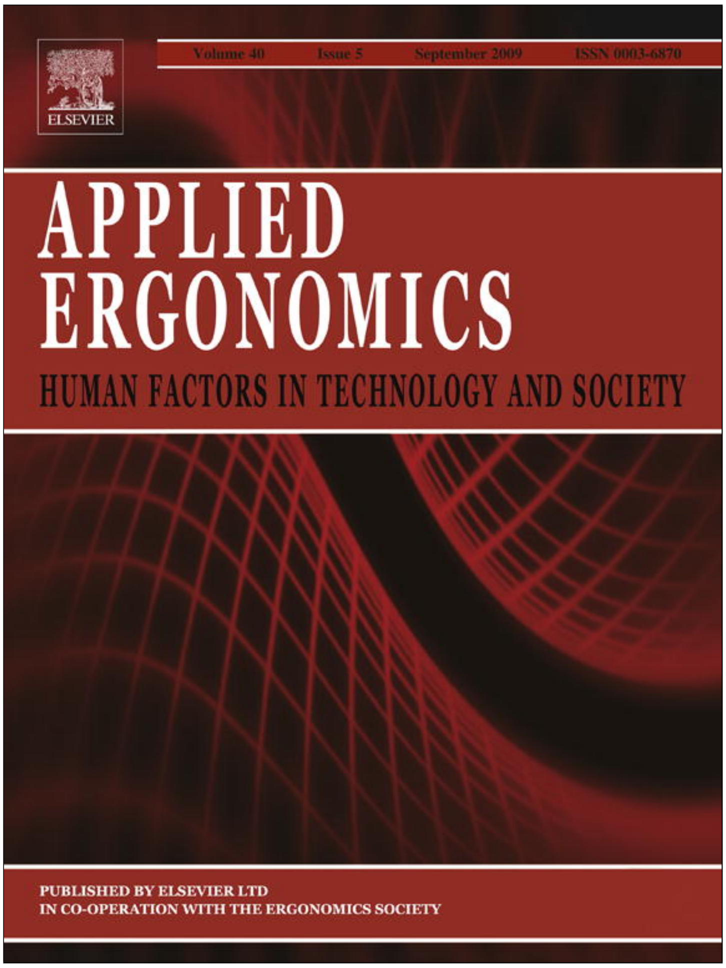

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Transfer of computer-based training to simulated driving in older adults

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ABSTRACT

As the population of many industrialized countries ages, the number of older drivers on the roads increases. Statistics show that older drivers are at increased risk for involvement in fatal accidents. One explanation for this is the cognitive and motor declines associated with the aging process. As we age, performance on attention, memory and motor control tasks, three important components of driving, declines. In the present study we examined the relationship between performance on component cognitive tasks and the influence of training on these tasks on the simulated driving performance of older adults. More specifically, we assessed performance on and trained older adults on single and dual tasks of attention, working memory and manual control. Regression analyses demonstrated that performance on the single and dual cognitive tasks and improvements in these computer-based tasks with training were predictive of improvements in driving simulator performance across the course of the study. These data suggest that relatively simple single and dual computer-based tasks and modest amounts of training on these tasks can improve driving performance in older adults, thereby extending functional independence.

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The population of the United States and indeed much of the industrialized world is aging. According to the U.S. Census Bureau's figures, the number of citizens over the age of 75 increased more than 25% between 1990 and 2000 (2000 United States Census, 2001). Along with this increase in population, there has been an increase in the number of older drivers.

Government figures from 2005 reveal that 39,189 people lost their lives in motor vehicle accidents. In terms of miles driven, two groups of drivers accounted for an inordinate proportion of these accidents: young drivers under 20 years of age and drivers over the age of 75. In 2005, young drivers accounted for 6.4 percent of total licensed drivers and 12.9 percent of driver fatalities. During the same period, older drivers accounted for 9.6 percent of licensed drivers and five percent of driver fatalities (Highway Statistics 2005, 2006; Traffic Safety Facts 2005, Final Edition, 2006). When scaled to account for number of miles driven, older drivers' risk for fatal accident involvement is nearly as high as that of novice drivers. The proportion of older drivers is increasing at a faster rate than the driving population as a whole. Based on 2000 census data, the general trend appears to be for a continued increase in the number of older drivers. Given these trends, it is important to gain an understanding of the factors involved in older drivers' risk for crashes and fatalities with an eye toward remediation of declines.

1.1. Contributory factors to increased risk of driving accidents

In a recent paper Anstey and colleagues (Anstey et al., 2005) reviewed sixteen studies, published between 1991 and 2002, investigating the effects of several factors on driving performance in older adults as measured by crash risk or on-road tests. The authors focused on studies which included measures of cognitive, visual sensory and physical factors. Significant cognitive factors included several measures of attention (including selective, divided, and visual attention), measures of perception (including visuo-spatial ability and perceptual speed), and measures of executive function. A study by McKnight and McKnight (1999) is representative of those reviewed by Anstey et al. The authors assessed drivers on a broad range of cognitive, sensory and perceptual abilities and measured their responses in a variety of driving behaviors during an on-road test. A composite measure of ability scores "correctly identified 80% of the incident-involved drivers while misidentifying 20% of incident-free drivers." Anstey et al. concluded that compared across studies, sensory abilities and physical fitness/health factors were less likely than cognitive factors to be associated with negative driving outcomes such as crash involvement or poor on-road driving performance. They proposed a multifactorial model of driving safety in older adults. The model is composed of two main factors: driving capacity and self-monitoring. In general, this model divides driver capacity (ability) into cognitive, visual and physical function factors. The

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authors note that factors such as movement speed, speed of response, working memory and attention are critical factors contributing to safe driving capacity. The present paper focuses on driver capacity.

Driving capacity refers to the ability to perform the basic tasks of driving a vehicle safely. This is directly related to specific cognitive and motor abilities. While there is some disagreement among researchers, a general view suggests that manual control (tracking), visual–spatial attention and working memory are all important components of the complex driving task (see Anstey et al., 2005; Groeger, 2000; Schlesinger, 1967). Unfortunately for older adults, performance on these abilities tends to decline with age. Manual tracking accuracy generally decreases with age (Korteling, 1991; Tsang and Shaner, 1998; Wickens et al., 1987). Visual attention also declines with increased age, most notably relevant to driving in the research of Ball, Owsley and colleagues on the Useful Field of View (UFOV®) task (Ball, 1997a,b; Ball et al., 1988; Ball and Owsley, 1991; Owsley et al., 1991; Roenker et al., 2003). Age-related declines in working memory are found consistently in cognitive aging research (Craik, 2000; Hartman and Warren, 2005; Salthouse, 1990, 1994, 2006).

1.2. Cognitive training

While the inevitability of these declines seems to bode ill for drivers, there is hope. Training on perceptual, cognitive and motor tasks has been shown to improve performance in those tasks in younger and older adults alike (e.g. Kramer et al., 1995, 1999). Furthermore, training on some tasks has been shown to persist over fairly long periods of time, even in older adults (Roenker et al., 2003; Vance et al., 2007). Thus, given such training effects on basic perceptual, cognitive and motor abilities it seems reasonable to speculate that training of such abilities might serve to compensate for age-related decline in a variety of aspects of cognition (Kramer and Willis, 2002). Indeed, this is one of the hypotheses that we examine in the present study by developing computer-based training tasks which include important components of driving. In the following section, we describe a training protocol referred to as Variable Priority Training, which has shown promise in improving performance and learning in situations in which individuals need to either concurrently perform multiple tasks or switch rapidly between different tasks or skills.

1.3. Variable priority training

Variable priority training is a hybrid training strategy which incorporates elements of part-task and whole-task training (Gopher et al., 1989; Yechiam et al., 2001). A complex task is divided into its component tasks as in part-task training, but participants are asked to perform the tasks together as in whole-task training. Under dual-task conditions, participants are asked to treat the tasks with different and varying priorities across different blocks of trials. Adaptive, individualized feedback is provided to participants to assist them in adjusting their processing priorities among task components. Compared to more traditional whole and part-task training procedures variable priority training has been shown to enhance retention, transfer of training to laboratory and real-world tasks and resistance of trained tasks to distractions and extra-task demands (Bherer et al., 2006; Gopher et al., 1989, 1994; Fabiani et al., 1989; Kramer et al., 1995, 1999; Yechiam et al., 2001). There appear to be at least two important benefits of variable priority training. First, it enables individuals to practice on components of a task while in the context of the complete task, thereby reducing processing demands encountered during initial learning and emphasizing the relationships among different task components. Second, variable priority training helps to develop crucial attentional control and management skills, enabling individuals to successfully shift priorities among task components. Given the demonstrated success of variable priority training this training protocol was used in the present study to train older adults on single and dual-task cognitive tasks related to driving performance and safety.

1.4. Transfer of training

While training on laboratory tasks does appear to improve performance on those tasks, the question of whether laboratory training effects can transfer to other tasks remains unresolved. Recently, Green and Bavelier (2003, 2006) (see also Basak et al., 2008) reported finding that participants trained on an action video game showed significant improvement in tests of visual attention. Transfer of training effects from a virtual training task to game performance has been found in tennis players (Smeeton et al., 2005). Smeeton et al. tested tennis player's reaction time and accuracy to various tennis shots in a laboratory setting and on the court both before and after training. Training involved responding to tennis shots projected in a laboratory. Relative to a control group, the trained participants improved in performance in the lab and on the court.

Gopher et al. (1994) found that training young adults with the variable priority training technique in individual tasks focused on manual control, attention, memory and the coordination of these processes in a video game called Space Fortress enhanced flight training performance of student pilots (see also Hart and Battiste, 1992; Shebilske et al., 2005). Both the Gopher et al. (1994) and Smeeton et al.'s (2005) studies demonstrated transfer of skill from a laboratory setting to real-world task performance. An important aspect of what subjects appear to have learned from these training studies was the ability to distribute their attention among concurrently performed skills and to shift processing priorities when necessary. The participants in these studies were young, and potentially highly motivated to learn a new skill or improve a developing one. The outcome may be different with older adults and a well-learned skill which may be declining due to cognitive changes.

To date, we are aware of few attempts to provide training to older drivers in order to improve driving performance. One such study provided speed-of-processing training on the UFOV task to high-risk drivers (Roenker et al., 2003). The authors showed that such training resulted in a reduction in the number of dangerous maneuvers among high-risk older drivers as compared to low-risk older drivers and high-risk drivers who received reaction-time training. This effect was present immediately following training and was retained for at least 18 months. While encouraging, the study failed to find similar effects in 7 other composite driving measures such as use of turn signals, lane changing, speed control and stopping position. This may be due in part to the nature of the on-road assessment and the subjective measures recorded by an observer. The inability to control the environment during on-road assessment and the subjective measures may have masked some effects. The use of a driving simulator, where the environment can be controlled and objective measures obtained, is an interesting and potentially important alternative to on-the-road driving assessment.

1.5. Present study

The present study's main objective was to investigate whether training in laboratory tasks would transfer to driving performance in older adults. The training tasks were chosen to represent three

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important aspects of driving: manual control, visual attention and working memory. The tasks were seen as analogues to related driving skills, namely the lateral/longitudinal control of a vehicle, peripheral detection/discrimination tasks and situation awareness, respectively. Based on previous findings of transfer of skill from trained laboratory tasks to real-world tasks (Gopher et al., 1994; Hart and Battiste, 1992), we expected to find such relationships between our laboratory tasks and simulated driving. To our knowledge, no such attempt has been made before in a controlled driving environment with objective measures. A finding of positive transfer would suggest that older drivers' driving performance could be improved by training with periodic boosters, potentially in the home. This may make them safer drivers and enable them to continue driving beyond the point at which they would otherwise need to cease driving for safety reasons.

We used a regression approach to investigate the contributions of three types of predictors on post-training driving performance. We examined the relative contribution of initial driving performance, initial cognitive-task performance, and cognitive-task training effects on post-training driving performance.

First, we predicted that pre-training driving performance would have the greatest influence on post-training driving performance. The processes involved in experienced driving are considered by many to be relatively automatic. Indeed Shiffrin and Schneider (1977) discussed driving toward an intersection as a potential practical use of their research on automaticity. Automaticity of many components of driving is at least an implicit assumption in driving research which compares drivers possessing varied levels of experience with one another. Automaticity on a task has been related to more stable performance on that task (e.g. Segalowitz, 2003). Older drivers have attained a high level of automaticity in basic driving skills by virtue of many decades of driving experience and this suggests stable driving performance. We therefore predicted that much of the variance in post-training driving performance would be accounted for by the initial (pre-training) driving performance measures. These initial (pre-training) driving measures were entered into the regression analysis first given their importance.

We further predicted that initial performance on the cognitive training tasks, both performed separately and concurrently, would emerge as a significant predictor of post-training driving performance. This prediction is consistent with the several models of driving mentioned earlier (Anstey et al., 2005; Groeger, 2000; Salvucci, 2006). Models of driving note significant roles for particular cognitive processes on driving performance. Manual vehicle control (lateral and longitudinal positioning) is related to manual tracking performance, which has been shown to decline with age (Korteling, 1991; Tsang and Shaner, 1998; Wickens et al., 1987). Attentional control and working memory processes are involved in situation awareness, monitoring, and event and object detection during driving.

Finally, we predicted that training effects on our tasks implemented on our desktop environment would emerge as significant predictors of post-training driving performance. This follows from the second prediction above and the findings of successful transfer of training by others (Gopher et al., 1994; Hart and Battiste, 1992). If initial performance on the training tasks is a significant predictor of post-training driving performance, then it follows that performance improvements, both on the individually trained tasks and on the ability to successfully coordinate these tasks when performed concurrently (i.e. attentional control or management skills engendered by variable priority training), should also predict post-training driving performance. Such a finding would be an important step in beginning to understand how the driving performance of older adults may be improved.

2. Method

2.1. Participants

Twenty-one participants, 11 male, 10 female, all with valid driver's licenses, were recruited through newspaper advertisements and recruitment presentations at local independent-living communities. Mean age was 71.7 years (s.d. = 6.9 years). All participants listed English as their primary language. Participants had an average of 14.7 years (s.d. = 2.8) of formal education and score above 52 on the MMSE dementia screening test. On average the participants had their drivers licenses for 55.8 years (s.d. = 7.3) and had driven an average of 11,814 miles in the previous year. One was left-handed, the rest were right-handed. Participants were paid $8 per hour for the time spent in the study.

2.2. Apparatus

2.2.1. Laboratory training program

All training tasks were administered on a standard PC with a 23″ diagonal flat-screen CRT monitor. Participants used a Logitech MOMO racing wheel and pedals (Logitech) to control the position of the tracking cursor. This wheel has six buttons on its face which participants used to respond to the working memory and attention tasks.

As they would in a vehicle, participants turned the wheel to control the horizontal movement of the tracking cursor. They controlled the vertical movement of the cursor with the accelerator pedal in an approximation of the operation of a vehicle.

2.2.2. Simulator hardware and software

This research was conducted using the Beckman Institute Driving Simulator at the University of Illinois. The fixed-based simulator, supplied by DriveSafety, Inc., consists of a 1998 Saturn SL positioned in a wrap-around (360°) projection screen. For this experiment, only the forward three projection screens (subtending approximately 210° of visual angle) were used. Six Epson PowerLite 703c projectors project the simulation onto separate screens. Seven PCs control the simulator. A two-channel sound system provided traffic and road noise in addition to engine sounds. An eighth PC interfaced with the simulator via a network connection and provided both a sound server and a relay control card.

The simulator dynamics and environments were coordinated with DriveSafety's Vection™ software Version 1.4.1. Driving environments and scenarios were created on a PC using DriveSafety's HyperDrive™ authoring software version 1.4.1. Ambient traffic and dynamics were controlled through programming scripts.

Two large red response buttons were installed in the simulator on the steering wheel at approximately the 10 and 2-o'clock positions. The simulator collects data on vehicle position, velocity and acceleration, control positions (steering angle, pedal positions etc.), scenario vehicle position and button presses.

2.3. Stimuli

2.3.1. Laboratory training program

The computer-based training program was divided into several different tasks that depend on attention, visuo-spatial working memory, manual control and their combination in dual-task conditions. Stimuli specific to each task will be discussed separately. The screen color was black. It was divided into seven discrete areas (see Fig. 1). The rectangular area subtending 10.8° horizontally and 8.8° vertically at the center of the display was used for the tracking task and is henceforth referred to as the *tracking area*. The rectangle was sized to occupy approximately one-third of the width

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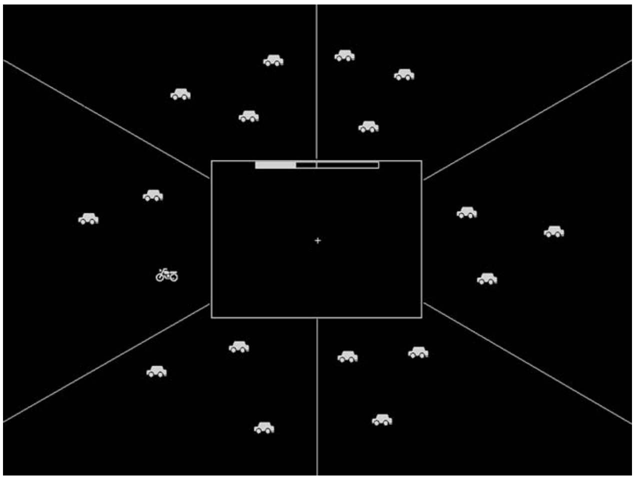

Fig. 1. The display during a typical trial for the selective attention task.

and height of the total display area. The remainder of the display screen was divided into six sextants encompassing 60° of arc on the monitor. Gray lines were used to delineate the boundaries of these sextants. The lines extended from the edge of the display to the edge of the tracking area, but did not extend into the tracking area. A small white fixation cross subtending 0.59° of visual angle was displayed at the center of the tracking area when participants were performing the visual selective attention or N-back single-task blocks. All stimuli in the training sessions were presented in light gray on a black background.

2.3.1.1.. Tracking task

A compensatory tracking task was employed in the study. The participant's goal was to keep a tracking target centered in the display. Participants used the steering wheel and pedals for this purpose. The white cross was placed at the center of the display. The tracking target was a white ring (subtending 0.59° of visual angle). Target movement was determined for each axis independently as the mean of ten sine waves of varying frequency (ranging from .08 to 2.49) and phase. The tracking cursor position was updated once per frame (frame rate was 60 Hz).

Feedback on tracking performance was provided. A gray progress bar (subtending 3.3° by 0.2° visual angle) appeared in the upper portion of the tracking display (see Fig. 1). The length of the bar indicated time-on-target for the preceding 4 s and updated once per second. RMS error and time-on-target were recorded as dependent variables. The bar's zero-position was at the left of the rectangular area represented in Fig. 1 and growth toward the center indicated better performance.

2.3.1.2.. Visual selective attention task

This task was modeled after the UFOV task (Ball, 1997a,b; Ball et al., 1988; Ball and Owsley, 1991; Owsley et al., 1991; Roenker et al., 2003). The UFOV task is used to assess spatial attention. Participants perform a central discrimination task as well as a peripheral detection and localization task. The visual selective attention task was designed to mimic the peripheral detection and localization tasks of the UFOV. The participant's task was to determine which of the six areas of the display contained the motorcycle and press the corresponding button on the steering wheel.

Distracters were side-view silhouettes of a typical sedan subtending 0.92° by 0.5° of visual angle; the target was a side-on silhouette of a motorcycle and subtended 0.98° by 0.59°. There were 3 items in each sextant on each trial; seventeen distracter cars and one target motorcycle. Stimuli were presented 7.5° and 10.0° of visual angle from the center of the display, with a small random variation in the actual positions. Target eccentricity was manipulated such that it was equally likely to appear at each eccentricity. The distracters were randomly assigned to one of the two eccentricities on each trial. A progress bar was displayed opposite the tracking progress bar and moved from left to right toward the center to indicate better performance. The length of the bar indicated accuracy over the previous ten responses and updated after each response. Accuracy and response time (RT) were recorded.

2.3.1.3.. Visual–spatial N-back task

The visual–spatial N-back task is a two-back running memory task and is used as a measure of working memory performance. The participant's task was to report whether the target on the present trial was displayed in the same location (sextant) as the target on two trials previously. The task was continuous in that after the first two trials in a block, on which no response was made, a response was required on every trial. This required participants to remember the location of the target on the previous two trials concurrently and to update the information on each trial. The response was made by pressing either the top-left (*different* trials) or the top-right (*same* trials) steering wheel button. A progress bar was displayed as described in the section above. Accuracy and RT were recorded as dependent variables.

The target stimulus for the N-back task was the same car silhouette as used in the visual selective attention task above. A single distracter was presented in each sextant that did not contain the target. The distracters were either squares (subtending 0.5° of visual angle) or triangles (subtending 0.53° by 0.5° of visual angle). Stimuli were displayed at a constant distance from the center of the display at approximately the center of the arc described by each sextant. As in the selective attention task, this task was force-paced and each trial lasted 2 s. The stimulus duration was determined by an adaptation session on an individual basis. This was done so that each participant's accuracy was the same when training began.

2.3.1.4. Dual tasks

Variable priority training was used during training. The tracking task was always performed. The visual selective attention and N-back tasks were paired with the tracking task for dual-task blocks. In the dual-task blocks, participants were asked to allocate a fixed proportion of their attention to the tracking task for each block type. The proportion was 20%, 50% or 80%. The remaining attention was to be allocated to the other task. Each priority level was used once for each block type during each session. For dual-task blocks, progress bar feedback in each task was scaled as a percentage of performance in the corresponding single-task block from the same session. Feedback was scaled such that when a task was emphasized 80%, full-scale performance was indicated when the participant attained performance (accuracy or time-on-target, depending on the task) equal to at least 80% of single-task performance in that task for that session. When a task was emphasized only 20%, participants were expected to attain only 20% of single-task performance.

2.3.2.. Driving simulator

The simulator tasks were chosen to represent several important components of driving; selective attention, visual working memory for items and events in the environment, manual control of the vehicle, and the ability to coordinate subsets of these tasks. Fig. 2 shows a representation of the driving environment.

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Fig. 2. A view of the driving monitoring task in the simulator. In this case, the image is at the 'near' position and the large size on the right-hand side of the driving scene. The image was chosen to resemble a construction barrier type of barrel.

2.3.2.1.. Car-following task

Car-following is a commonly used task in driving research as it provides a way to measure longitudinal vehicle control in addition to lateral control. In this case, a headway-maintenance task was used to test transfer of training from the computer-based training tasks (see above) to driving performance. Participants were asked to maintain a constant distance (49 m) from a lead vehicle while driving along a straight (no curves or turns) rural road. The brake lights on the lead vehicle were disabled to prevent an early warning during lead-vehicle deceleration which would not be available during vehicle acceleration.

The lead vehicle's base speed was approximately 104.6 km/h (65 miles/h). Approximately every 20 s, the lead vehicle's speed changed by either 16.1 km/h or 24.1 km/h (10 or 15 miles/h). On half of the trials, speed increased; on the other half of the trials speed decreased. The speed change lasted for 20 s at which point the lead vehicle's speed returned to the base speed.

A lateral moment of force was applied at intervals to simulate windy conditions. This was done to increase the realism of the driving task. This simulated that wind changed the participant's heading enough to require steering input to keep the vehicle in the proper lane.

2.3.2.2.. Visual memory task

This task was used to provide an index of visual working memory during driving, such as remembering information viewed while driving between different locations. The participant was asked to note the color of passing vehicles. As vehicles passed, the participant reported (via button press) whether the color of the current vehicle was the same or different from the color of the vehicle passed previously. Responses were recorded for later analysis. The timing of the task was such that a vehicle passed approximately once every 2.5 s. Vehicles could be red, blue, green or yellow. During single-task blocks, the participant responded to the vehicles, but was not in control of the car. Rather, the vehicle motion was achieved through playback of a pre-recorded drive by an experimenter. This was to make the single and dual-task blocks as similar as possible. Vehicles passed the participant vehicle (traveling in the opposite direction).

2.3.2.3.. Monitoring task

The monitoring task was used to provide an index of visual scanning and object detection during driving. A small graphic resembling a construction-type barrel (see Fig. 2) was superimposed over the driving scene. The transparency of the figure was set at 20% so that it was moderately difficult to detect. The figure was displayed at either 6.3° or 8.7° to the left or right of the driver's centerline. In addition, the image was displayed as either a large (3.6° tall by 4.3° wide) or small (1.8° by 2.15°) image. The image was displayed for 700 ms or 800 ms. Image side, eccentricity, size and duration varied randomly on each trial.

A trial consisted of the onset and offset of the image followed by the participant's response. Participants responded to the appearance of the image by pressing a button on the steering wheel indicating the side of the scene on which the image had appeared. The inter-trial interval (ITI) varied randomly from a low of 5 s to a high of 11 s.

2.3.2.4.. Dual tasks

As in the computer-based training program, the car-following, memory and monitoring tasks were all performed individually under single-task conditions. Both the memory and monitoring tasks were also paired with the car-following task. Participants were free to allocate attention as they saw fit with the stipulation that they were to treat driving as the primary task.

2.4.. Procedure

The experiment consisted of two initial driving sessions, followed by eight computer-based training sessions (with the manual control, visual selective attention and visuo-spatial N-back tasks and their combination with variable priority training) and two final driving sessions. The present study was undertaken as an initial investigation of the utility of various predictors of driving performance. To that end, we decided to devote all of our resources to the training group and to use a regression approach to examine the relationship between predictors and driving performance changes.

Each session took place on a different day. After obtaining consent and collecting demographic information, participants were instructed regarding the tasks they would perform in the simulator. They then drove a series of short practice drives to familiarize them with the simulator and side tasks. Participants were reminded periodically of the symptoms of simulator sickness and asked if they were experiencing any such symptoms.

Following the practice scenarios, participants drove the baseline experimental drives. The car-following single task was always first, followed by the memory and monitoring single tasks, and finally the two dual-task conditions combining the tracking task with the memory and monitoring tasks in that order. Measures from these tasks formed the baseline driving and side-task performance measures.

Participants then took part in the computer-based training. They were instructed in performing the tasks and allowed time to practice the tasks to ensure that they understood the instructions. On the first training day only, just prior to the training session, an adaptation procedure was performed to determine the duration of the target display during the selective attention and visuo-spatial N-back tasks. Using a QUEST algorithm (Watson and Pelli, 1983), the stimulus duration was set such that accuracy in the task was approximately 50% in the single-task condition. Stimulus duration was determined separately for each participant on each task (selective attention and visuo-spatial N-back) and did not change for the remainder of the training sessions.

Each training session consisted of the three single-task conditions, followed by six dual-task conditions in a fixed order with varying emphasis and ending with the three single-task conditions again. Self-timed rest periods were provided after each block in a particular task. Each session took approximately 90 min. After the

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final training session, participants returned to the driving simulator for the remaining two sessions, which were identical to the first driving sessions.

3. Results

Data from the present study were primarily analyzed by means of regression analyses. In order to demonstrate that the training was effective in improving performance on the single and dual-task, training-task data were analyzed with analysis of variance. Only single-task ANOVA results are discussed here, but means and standard errors for both single and dual-task conditions are presented in Table 1.

3.1. Training data

Response accuracy and RT were measured in the selective attention and N-back tasks. Root mean square tracking error and time-on-target were analyzed for the tracking task. The data were submitted to Analysis of Variance (ANOVA) with training session (1–8) as a within-participants factor to evaluate training improvements. If the training was effective RT should decrease and accuracy should increase from the first to the last session. Training-task data are presented in Table 1.

3.1.1. N-back task

Results revealed a main effect of session for both accuracy ($F(7,133) = 21.183$; $p < 0.05$) and response time ($F(7,126) = 30.1$; $p < 0.05$) in the single-task condition. As illustrated in Table 1, RT decreased and accuracy increased across training sessions. Table 1 includes data from single-task and dual-task conditions.

3.1.2. Selective attention task

A main effect was obtained for training session for both accuracy ($F(7,133) = 52.5$; $p < 0.05$) and reaction time ($F(7,133) = 10.8$; $p < 0.05$) in the single-task condition. As illustrated in Table 1, RT decreased and accuracy increased across sessions. Table 1 includes data from single-task and dual-task conditions.

3.1.3. Tracking task

Tracking-task data were analyzed with a 2-way ANOVA with training session (1–8) and task condition (tracking/N-back vs. tracking/selective attention) as within-subjects factors. For the tracking/N-back combination main effects were obtained for session ($F(7,140) = 6.16$; $p < 0.05$) and task condition ($F(1,20) = 62.2$; $p < 0.05$) factors. As illustrated in Table 2, RMSE declined across session and was smaller for the single than for the dual-task conditions. For the tracking/selective attention combination main effects were obtained for session ($F(7,140) = 8.48$; $p < 0.05$) and task condition ($F(1,20) = 51.2$; $p < 0.05$). As illustrated in Table 2 RMSE declined with session and was smaller for the single than for the dual-task conditions. Similar results are evident for the time-on-target measure in each condition.

3.2. Driving simulator tasks

Driving performance was characterized by examining lane position, following distance and accelerator response to lead-vehicle braking. As driving performance could be expected to be fundamentally different while the lead vehicle's speed was changing vs. when its speed was steady, data during speed-change events were analyzed separately from steady-state data. Lane position and following distance were assessed in terms of root mean square error (RMSE). Lane position ranges from -1.7 m to $+1.7$ m, with zero being the center of the lane. The target following distance was 49 m. Response time to lead-vehicle brake events (accelerator response time or aRT) was measured in milliseconds. Side-task performance was assessed by analyzing RT, as accuracy was uniformly high. In the driving monitoring task, preliminary analyses revealed no significant differences between the side of presentation or size of the target patch, so these factors were collapsed in the regression analyses which follow.

3.3. Regression analyses

We performed regression analyses to address the relative contributions of the three classes of predictors mentioned earlier: initial (pre-training) driving performance, initial training-task performance and training effects. As discussed, initial driving performance was predicted to account for much of the variance in final driving performance due to the relatively automatic nature of the component tasks of driving and the high degree of automaticity attained by our experienced older drivers. Initial training-task performance was predicted to account for a significant portion of the variance in driving performance due to the relationship, at a conceptual level, between the training tasks and the associated component tasks in driving. Training effects were predicted to account for an additional, though probably small, portion of variance. Given the large expected contributions from the initial performance predictors, even a relatively small portion of predicted variance would be an important result as it would demonstrate the possibility that training induced improvement in performance in laboratory-based cognitive tasks can positively influence performance in a complex real-world task such as driving.

For each participant, driving measures from the first driving session corresponding to the dependent final-session measure (e.g., if we were predicting RMS lane position error, we included RMS lane position error in the first driving session) and performance in the first training session for the computer-based training tasks were entered into the model first. Training variables included were

Table 1
Mean (s.e.) accuracy and RT in memory, selective attention and N-back tasks.

Task	Measure	Session 1	2	3	4	5	6	7	8
Selective attention task	Accuracy (% correct)	61 (3.3)	66 (4.0)	70(3.9)	75 (4.1)	76 (4.2)	76 (4.2)	79 (4.3)	78 (4.4)
	RT (ms)	1175 (28.9)	1135 (28.6)	1137 (24.3)	1110 (24.1)	1093 (22.8)	1087 (26.3)	1062 (27.9)	1066 (27.9)
N-back task	Accuracy (% correct)	55 (4.0)	62 (4.4)	64 (4.3)	69 (4.3)	72 (4.0)	73 (4.4)	75 (4.4)	74 (4.6)
	RT (ms)	958 (38.7)	875 (36.6)	824 (42.8)	794 (38.7)	781 (39.6)	731 (32.8)	709 (34.3)	721 (31.8)
Selective attention task/tracking	Accuracy (% correct)	56 (3.2)	65 (3.9)	66 (4.2)	70 (4.3)	74 (4.5)	75(4.2)	77 (4.3)	76 (4.3)
	RT (ms)	1192 (34.0)	1156 (33.9)	1146 (28.4)	1129 (27.6)	1112 (27.3)	1101 (30.6)	1078 (33.0)	1077 (34.0)
N-back task/tracking	Accuracy (% correct)	63 (4.2)	66 (4.7)	69 (4.4)	72 (4.0)	74 (4.5)	75 (4.6)	77 (4.6)	75 (5.0)
	RT (ms)	927 (40.9)	861 (37.7)	824 (40.3)	807 (37.3)	771 (34.7)	766 (36.1)	736 (31.5)	759 (34.2)

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Table 2
Mean (s.e.) RMS error and time-on-target in the tracking task.

Task	Measure	Session							
		1	2	3	4	5	6	7	8
Tracking	RMSE (pixels)	37.44 (1.03)	37.52 (1.07)	37.02 (0.98)	36.25 (1.01)	36.64 (1.09)	35.89 (1.12)	35.43 (1.15)	35.22 (1.15)
	ToT (s)	30.72 (1.58)	30.60 (1.59)	30.85 (1.46)	32.75 (1.83)	32.26 (2.02)	33.74 (2.15)	34.68 (2.21)	35.15 (2.21)
Tracking/attention	RMSE (pixels)	43.53 (1.18)	42.33 (0.88)	42.09 (0.87)	41.56 (0.80)	42.64 91.12)	41.33 (1.19)	41.28 (1.10)	40.32 (1.17)
	ToT (s)	22.58 (1.35)	24.00 (1.03)	24.15 (1.13)	24.94 (1.00)	23.12 (1.45)	25.80 (1.41)	25.60 (1.52)	26.90 (1.51)
Tracking/N-back	RMSE (pixels)	42.91 (1.13)	41.94 (0.75)	43.28 (1.28)	41.67 (1.25)	41.95 (1.14)	41.22 (1.06)	39.83 (1.02)	40.29 (1.27)
	ToT (s)	23.10 (1.29)	23.48 (0.98)	22.87 (1.42)	25.08 (1.52)	24.42 (1.49)	25.56 (1.57)	27.41 (1.64)	27.18 (1.78)

first-session RT and accuracy in single and dual-task conditions for the N-back and selective attention tasks as well as single-task RMS tracking error. Due to a high correlation among the tracking-task measures, only the single-task RMS tracking error was included in the forced factors. These variables were entered first to account for the variance explained by initial driving and computer-based training-task performance. Thus, we asked whether initial driving performance as well as baseline performance on the computer-based training tasks accounted for significant amounts of variance in final simulated driving performance before examining the additional predictive value of computer-based training benefits on the selective attention, N-back, tracking, and dual-task combinations of these tasks.

After the baseline measures were entered, a stepwise regression was performed using computer-based training effect sizes as predictors. For the tracking task, RMS error and standard deviation of time-on-target (TOT) were used as measures. For the selective attention and N-back tasks, accuracy and RT were used. Effect sizes were calculated by subtracting the first-session, first-block single-task performance score from the final-session, and final-block single-task performance score and dividing this difference by the pooled variance for each measure. Thus improvements in accuracy and time-on-target are positive scores, while improvements in RT and tracking error are negative scores. The significance level for entry into the model was set at 0.05.

Regression results are presented in Table 3. Variance predicted by first forced factor (i.e., baseline driving performance) ranged from a low of 7.5% to a high of 68.5 %. Additional variance predicted by baseline performance on the computer-based training tasks ranged from a low of 28% to a high of 75%. However in all but one case this was not a significant contribution. This lack of significance may be due to the wide range of performance in the training tasks. Combined, initial driving performance in the simulator and baseline performance on computer-based training tasks accounted for substantial variance in the drivers' performance on the final driving test.

Importantly, a number of the measures of improvements in performance on the computer-based training tasks also accounted for significant residual variance in driving performance on the final driving test. These predictors included: attention dual-task effects in the RMS lane position driving measure, and RMS tracking error, attention single and dual-task effects, and memory single and dual-task effects in accelerator release time in the following and monitoring and following and memory driving measures. These effects are discussed further in the subsequent paragraphs.

RMSE lane position in the car-following/monitoring dual-task condition was influenced by size of the accuracy effect in the training attention task. Initial driving performance factors accounted for 42.8% of the variance, initial training factors for an additional 47.9%. The attentional dual-task effects for accuracy and RT effect sizes accounted for 9.3% of the variance in final driving performance. A larger training effect size was associated with less lane position error, or better lane tracking performance. There were no significant contributions of training effects to RMS Lane position in the following and memory task.

Accelerator response time in the car-following/monitoring dual-task condition was influenced by RMS tracking error, memory and attention computer-based training tasks. Initial driving factors accounted for 53.6% of the variance and baseline training-task factors for an additional 38.3% of the variance. Improvements in performance on RMS tracking, memory, and attention computer-based tasks accounted for an additional 8.2% of the variance in the accelerator response time driving measure. These improvements in computer-based training tasks were related to faster accelerator RT in the final driving test.

Accelerator response time in the car-following/memory dual-task condition was influenced by improvements in the memory and attention computer-based training tasks. Initial driving factors accounted for 7.5% of the variance and initial baseline training factors for 75.2%. Attention and memory task effect sizes accounted for an additional 17.2%. Improvements in the performance of the attention and memory computer-based training tasks resulted in faster accelerator response time in the car-following/memory dual-task condition.

There was a significant effect of initial driving performance on RMS following distance in the following-only condition, but no other effects were obtained for this measure.

4. Discussion

The present study is one of the few to examine transfer of training from computer-based training tasks to simulated driving in older adults (Hendel, 2003; Regan et al., 2007; Roenker et al., 2003). As hypothesized, initial (pre-training) driving performance predicted most of the variance in final (post-training) driving performance. Moreover, initial performance in the computer-based training tasks also predicted substantial variance in post-training driving performance, although not significantly so in most cases. The lack of significance of initial training-task performance may stem from considerable individual differences in initial performance on these tasks as well as the relatively small sample size. However, it is the contribution of the training *improvement* which is of greater interest in the present context.

The regression results showed that computer-based training of older adults on relatively simple perceptual and cognitive analogs of aspects of driving can produce significant improvements in selected aspects of simulated driving performance. Furthermore, these training effects can be observed after accounting for initial levels of simulated driving performance as well as initial (baseline) levels of performance on the computer-based training tasks. The predictive effects of computer-based training are admittedly small, but nonetheless significant. In all cases where a significant effect was found, training effect measures were directly related to final-session driving performance measures, indicating transfer of

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Table 3
Regression statistics.

Predicted variable	Stage	R	R^2	ΔR^2	ΔF	Sig. ΔF
RMS lane position (car following only)	Initial driving performance	0.768	0.590	0.590	12.946	0.000*
	Initial training-task performance	0.997	0.995	0.405	21.716	0.004*
RMS lane position (following and monitoring)	Initial driving performance	0.654	0.428	0.428	6.735	0.007*
	Initial training-task performance	0.952	0.907	0.479	1.464	0.385
	Attention dual-task RT effect	*0.993*	*0.985*	*0.079*	*16.310*	*0.027**
	Attention dual-task accuracy effect	*1.000*	*0.999*	*0.014*	*34.378*	*0.028**
RMS lane position (following and memory)	Initial driving performance	0.828	0.685	0.685	19.583	0.000*
	Initial training-task performance	0.982	0.965	0.280	2.271	0.222
RMS following distance (car following only)	Initial driving performance	0.614	0.377	0.377	5.443	0.014*
	Initial training-task performance	0.964	0.930	0.553	2.265	0.223
RMS following distance (following and monitoring)	Initial driving performance	0.322	0.103	0.103	1.039	0.374
	Initial training-task performance	0.871	0.759	0.656	0.779	0.677
RMS following distance (following and memory)	Initial driving performance	0.478	0.229	0.229	2.671	0.096
	Initial training-task performance	0.875	0.766	0.537	0.656	0.751
Accelerator RT (car following only)	Initial driving performance	0.466	0.217	0.217	5.257	0.033*
	Initial training-task performance	0.883	0.779	0.562	0.909	0.597
Accelerator RT (following and monitoring)	Initial driving performance	0.732	0.536	0.536	21.930	0.000*
	Initial training-task performance	0.958	0.919	0.383	1.679	0.296
	RMS tracking error single-task effect	*0.996*	*0.992*	*0.074*	*39.242*	*0.003**
	Memory dual-task accuracy effect	*0.999*	*0.999*	*0.007*	*19.373*	*0.022**
	Attention single-task accuracy effect	*1.000*	*1.000*	*0.001*	*25.086*	*0.038**
Accelerator RT (following and memory)	Initial driving performance	0.274	0.075	0.075	1.540	0.230
	Initial training-task performance	0.910	0.827	0.752	1.558	0.328
	Attention single-task RT effect	*0.982*	*0.965*	*0.137*	*15.624*	*0.017**
	Memory single-task RT effect	*0.997*	*0.993*	*0.029*	*13.195*	*0.036**
	Attention dual-task RT effect	*1.000*	*1.000*	*0.006*	*24.147*	*0.039**

training from the computer-based tasks to improvements in simulated driving. This is especially important considering the relative simplicity of the training tasks as measures of manual control, attention, working memory as well as the ability to perform these tasks together.

A significant effect of attention training tasks was found on RMS lane position error in the following and monitoring driving task. However, no significant effect of memory training tasks was found in the following and memory driving task. Note that significant effects of the memory training task were only found in the accelerator RT results, discussed below. It may be the case that the memory task in the driving simulator was not sufficiently difficult to tax the participant's resources to the point where a beneficial effect on driving performance would become evident. Increasing the difficulty of the memory training task or increasing the cognitive load on the participant may produce a significant contribution of the memory training to driving performance measures. Indeed, this is supported by the discussion of the accelerator RT results below.

Few effects were found with regard to the car-following distance measure. In retrospect, this is not all that surprising. There was large variation in the actual following distance maintained by participants during the drives. There were differences across participants as well as within participants during each driving task. This may have contributed to interesting effects in the accelerator RT results.

Accelerator RT results demonstrated cross-task performance effects. That is, memory-related training effects were found to contribute significantly to the car-following and memory driving results. Moreover, no training effects contributed to accelerator RT in the car-following-only condition. This may seem cause for concern at first, but upon further consideration, it seems reasonable. Performance on this task involves manual control, memory, attention, and multi-tasking abilities. The participant is required to maintain a following distance and respond to the potential slowing of the lead vehicle, which involves not only attending to the vehicle's relative position but remembering its position over time, which taps working memory. Regardless of side task, responding to the lead vehicle by releasing the accelerator and/or applying the brake taps more processes than maintaining lane position or following distance. Recall that following distance measures were taken during periods in which the lead vehicle's speed was in a steady state. In essence, the accelerator RT measure is measuring performance during a task which constituted an additional load on both attention and memory over and above the actual side task being performed at the time. Therefore considerable cross-task performance effects are not surprising.

The present results are in agreement with other studies in older adults which find improvements in performance with practice and training. For instance, a training study performed within the Seattle Longitudinal Study (Schaie, 2005) showed that after only 5 h of training on cognitive tasks such as spatial rotation, older adults showed measurable improvements in performance. These improvements persisted at follow-up seven years later. Training, however, was highly ability-specific: training on mental rotation did not transfer to performance of other tasks and skills such as inductive reasoning. Another long-term study found similar results. The Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study found that training on reasoning, memory, and attentional speed improved the performance of older adults on the respective tasks (Willis et al., 2006). The training improvements, with occasional booster training, persisted over a time interval as long as five years. Other studies have shown improvements in driving measures related to cognitive training (Hendel, 2003; Roenker et al., 2003). Roenker et al. (2003) found that at-risk older drivers who received speed-of-processing training made fewer dangerous maneuvers during an on-the-road driving test than individuals provided with training in a driving simulator.

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Our research extends these findings by showing that training on tasks that tap selective attention, working memory, manual control and the concurrent performance of these tasks and skills can also improve driving performance – even after accounting for baseline driving performance and baseline performance on the cognitive training tasks. One important aspect of our training, consistent with conclusions from the literature on variable priority training (Bherer et al., 2006, 2008; Gopher et al., 1994; Kramer et al., 1995, 1999), is that subjects learn to better manage their attentional resources; and it is improvement in this attentional control or management skill that transfers to driving. Indeed, driving entails the coordination of tasks including monitoring for pedestrians and other vehicles, lane keeping, route planning, and other extra vehicular tasks such as talking with passengers, adjusting the radio, etc. Clearly, attentional management skills, which older adults often perform poorly (Kramer and Madden, 2008), are needed to coordinate the multiple sub-skills that are required for safe driving.

Beyond the safety issues for older drivers and others on the road, the social and mental-health implications for the elderly driver and his or her family are immense. Cessation of driving is a major life event. Negative effects of driving cessation on feelings of independence are common because of the necessary dependence on others for transportation and the need to pre-plan trips (Adler and Rottunda, 2006). Those living in urban areas served by mass transit are often reluctant to use it (McKnight, 2003; Straight, 2003). Those living in rural areas typically have far fewer options, increasing feelings of isolation. Driving cessation also typically impacts other members of the older driver's family as they are increasingly called upon to provide transportation for routine daily-living activities (Dugan, 2006). If, as seems likely, some of the driving-related problems faced by older drivers are due to cognitive declines which respond to training, it may be possible through targeted training to extend their freedom and independence while increasing road safety for all drivers.

In addition to so-called 'normal' aging, the cognitive impact of degenerative neurological disorders such as Alzheimer's, Parkinson's, or Huntington's diseases impact driving safety (Uc et al., 2004, 2006). Cognitive training can improve cognitive performance at least to some extent in cases of mild dementia or mild cognitive impairment (Mate-Kole et al., 2007; Talassi et al., 2007). Whether training improvements can transfer to driving or not in such cases remains to be seen. The issue certainly merits further investigation.

There is another demographic group at high risk for collision; young, novice drivers. These drivers are generally most at risk for fatal collisions, presumably due to the lack of experience and still-developing executive control functions (McKnight and McKnight, 2003). While younger adults were not the subject of the present study, young novices may indeed benefit from similar training to speed the development of the skills and abilities tapped by driving. That is not to say that such training would be a panacea; the decision-making skills of young adults may not respond to training in this fashion, leaving many opportunities for dangerous behaviors while driving. In addition, the present results suggest that any driver suffering from cognitive decline may benefit from training to improve the specific abilities related to driving.

While the present findings are exciting, additional research is required to further elucidate the relationship between aging and driving performance and safety. First, our study provided a relatively modest amount of training on the single and dual tasks. Whether additional training would yield larger driving benefits is an open question for future research. Second, although our selection of training tasks was based on a decomposition of the skills required for driving and the literature on age-related perceptual and cognitive change an examination of the utility of training a broader set of perceptual, cognitive and motor skills is warranted. Third, the older adults who served in our study were relatively young. Given that the fastest growing portion of our population is those 80+ years of age it will be important in the future to determine whether training strategies like those that we employed apply to this group of potential drivers. Fourth, our training was individualized and adaptive in terms of the performance feedback that was presented to participants. However, whether further individualization of training, such as a focus on the perceptual and cognitive abilities where individuals show the greatest age-related deficit, would further enhance driving performance and safety is an important question for future research. Fifth, the addition of a control group which receives equivalent amounts of training on tasks not expected to positively influence driving performance and safety should be included in future studies. Such a control group would help to further establish that training on the cognitive tasks is directly related to improvements in driving performance and safety. It might be suggested that in the absence of a control group our results may be attributed to increased familiarization with the driving simulator. However, this appears unlikely since we found that the amount of improvement on the driving tasks was linearly related to the amount of improvement observed for the cognitive training tasks. Nevertheless randomized studies with both training and control groups would further establish the relationship between cognitive training and driving. Finally, it will be important in future studies to examine the relationship between improvements in driver performance that are engendered by training interventions like the one that we have examined and changes in their confidence concerning safe driving. A crucial issue here is whether changes in confidence are appropriate given the magnitude of change in objectively measured driver performance and safety.

In summary, the present results are an important first step toward improving the safety and prolonging the independence of older drivers, but more work remains to be done. Ultimately, the goal of this program of research is to be able to provide the older driver with a computer-based tool which can be used periodically in the home. The intent is to boost cognitive performance and so extend the functional independence of older adults by safely postponing cessation of driving.

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