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The Role of Visual Attention in Predicting Driving Impairment in Older Adults

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This study evaluated the role of visual attention (as measured by the DriverScan change detection task and the Useful Field of View Test [UFOV]) in the prediction of driving impairment in 155 adults between the ages of 63 and 87. In contrast to previous research, participants were not oversampled for visual impairment or history of automobile accidents. Although a history of automobile accidents within the past 3 years could not be predicted using any variable, driving performance in a low-fidelity simulator could be significantly predicted by performance in the change detection task and by the divided and selection attention subtests of the UFOV in structural equation models. The sensitivity and specificity of each measure in identifying at-risk drivers were also evaluated with receiver operating characteristic curves.

Keywords: attention, aging, driving, DriverScan, UFOV

The problems of older drivers have been noted anecdotally and empirically for many years. Next to the youngest drivers, older adults have the highest rate of accidents per mile driven, particularly after age 70 (Levy, Vernick, & Howard, 1995; Morgan & King, 1995; Ryan, Legge, & Rosman, 1998; but see Hakamies-Blomqvist, Raitanen, & O'Neill, 2002; Janke, 1991) and are more likely to suffer serious injury or death in an accident (O'Neill, 2000). The accidents of older adults most often involve right-of-way violations, such as when negotiating intersections and merging with traffic (McGwin & Brown, 1999; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998). The number of older adults in the driving population is expected to increase rapidly in the coming years, such that by 2024, it is estimated that adults over 65 will constitute 25% of the country's drivers (Owsley, 1997). Given the great variability among older adults in their rates of decline and the costs in terms of mobility and emotional well-being that the loss of driving privileges can create (Marottoli et al., 2000), development of reliable methods with which to identify drivers who may be impaired has become increasingly important.

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Many visual difficulties occur with age, such as declines in acuity, contrast sensitivity, retinal illumination, and accommodation of the lens; increased susceptibility to glare; and peripheral field loss (Fozard & Gordon-Salant, 2001). Despite the presumed importance of visual abilities in driving, however, small or negligible relations have been reported between accident risk and static acuity in older adults (Johnson & Keltner, 1983; Kline et al., 1992; Staplin, Lococo, Stewart, & Decina, 1999). Similarly, although many studies have examined the relation between driving impairment and disease status (e.g., cardiovascular disease or Alzheimer's disease, Lloyd et al., 2001; Waller, 1992), functional status (e.g., walking frequency or history of falling, Marottoli, Cooney, Wagner, Doucette, & Tinetti, 1994; Sims, Owsley, Allman, Ball, & Smoot, 1998), and cognitive status (e.g., Mini-Mental State Examination or Mattis Organic Mental Status Syndrome Examination [MOMSSE], Ball & Owsley, 1993; Johansson et al., 1996), the obtained relations have not been of sufficient magnitude to be useful for distinguishing safe from unsafe drivers. Although dynamic visual acuity, contrast sensitivity, and motion perception may be better predictors of accidents in older adults, (Schneider & Pichora-Fuller, 2000; Shinar & Schieber, 1991), another dimension likely to be relevant is visual attention.

Visual Attention and Driving Impairment in Older Adults

The most systematic program of research examining visual attention in the context of driving impairment is that using the Useful Field of View Test (UFOV), described by Ball, Owsley, and colleagues as assessing the spatial extent of the attentional window (Ball, 1997; Ball & Owsley, 1993; Ball & Rebok, 1994; Owsley, 1994; Owsley, Ball, & Keeton, 1995; Owsley, Ball, Sloane, Roenker, & Bruni, 1991). The UFOV has three subtests. The processing speed subtest is a central target discrimination task and does not require distribution of attention across the visual field. The divided attention subtest pairs the same central discrimination task with a concurrent peripheral localization task (targets are presented at 30° eccentricity). In the selective attention subtest, the central discrimination and peripheral localization tasks are performed in the presence of 47 triangles arranged randomly across the 30° visual field. Thus, in both the divided and selective attention subtests, attention must be distributed to some degree across the visual field in order for both tasks to be performed correctly. Presentation time is increased after each incorrect response and decreased after two consecutive correct responses, and a threshold of 75% correct is determined for each subtest by the geometric mean of the durations for five consecutive correct–incorrect reversals. Although each subtest has different attentional requirements, the obtained thresholds are combined into a single measure expressed as the percentage of reduction in the visual field from 0 to 90 (see Edwards et al., 2005), as well as an ordinal measure of automobile accident risk derived from group norms, ranging from 1 (*very low risk*) to 5 (*very high risk*).

In a study by Owsley et al. (1991; also reported in Ball & Owsley, 1993) 52 drivers between the ages of 57 and 83 were recruited from an optometry clinic and assessed on eye health, visual function, and cognitive status (using MOMSSE). The UFOV was assessed as pass/fail; failure was defined as an inability to perform any task with at least 75% accuracy at 250 ms. A structural model accounted for 20% of the variance in accident frequency within the past 5 years, with significant direct paths from eye health to visual function, from visual function and cognitive status to UFOV, and from cognitive status and UFOV to accident frequency. Failure on the UFOV correctly identified 11 of 12 persons who had had an accident and correctly rejected 26 of 40 persons who had not.

This model was replicated in Ball and Owsley. (1993; also reported in Ball & Rebok, 1994; Goode et al., 1998; Owsley et al., 1998), in a study in which 294 community-dwelling, licensed drivers between 55 and 90 were sampled and stratified for age and accident frequency during the previous 5 years. Only accidents in which independent raters agreed that the driver had some responsibility were analyzed. Each measure had a significant bivariate relation to accident frequency; the strongest was the UFOV (r = .52). A structural model accounted for 28% of the variance in accident frequency, with significant direct paths from visual function and cognitive status to UFOV and from cognitive status and UFOV to accident frequency. A 40% reduction in the UFOV had sensitivity (i.e., hit) and specificity (i.e., correct rejection) rates of 89% and 81%, respectively. The sample was then followed for 3 years, and the same structural model was able to account for 22% of the variance in prospective accidents; 40% reduction in the UFOV had sensitivity and specificity rates of 94% and 65%, respectively (Ball, 1997; Owsley, 1994).

Although these findings are encouraging regarding the usefulness of the UFOV for predicting driving impairment, several concerns relating to the construct validity and predictive utility of the UFOV should be noted. The first concerns the appropriateness of combining scores from the UFOV subtests into a single measure, given that each task has different attentional requirements, and thus a composite measure may not be theoretically or empirically justified. It may be that scores on individual subtests are better predictors of driving than the composite score.

A second concern is the sensitivity of the UFOV to presumed deficits in the breadth of attention, given that the scale of attention can only be measured in conditions of "near" (i.e., for central discrimination) or "far," since peripheral target eccentricity is fixed at 30°. Older adults have been characterized as having *tunnel vision* (Mackworth, 1965) or a reduced *useful field of view* (Saunders, 1970; Ball, Beard, Roenker, Miller, & Griggs, 1998; Scialfa, Kline, & Lyman, 1987; Sekuler & Ball, 1986) because they make more frequent peripheral localization errors than younger adults; however, in order for this interpretation to be correct, older adults would need to show decreasing performance specifically as a function of peripheral target eccentricity within a given stimulus condition, not just worse performance overall.

Although the UFOV task cannot test this interpretation, several experiments have investigated the extent to which older adults are differentially affected by target eccentricity. Seiple, Szlyk, Yang, and Holopigian (1996) found decreased accuracy with increased task difficulty (i.e., backward-masked central target and peripheral distractors) and greater peripheral target eccentricity. Yet older adults were *not* differentially affected by eccentricity as compared to younger adults within the same condition. Reexamining the results of Ball et al. (1998) leads to a similar conclusion; although the difference between older and younger adults increased with task difficulty, a similar effect of eccentricity was found for each within the same condition. Sekuler, Bennett, and Mamelak (2000) found that central task performance decreased linearly with age after 40; peripheral task performance declined linearly across all ages. Although performance in the peripheral task in the dual task condition decreased with age and eccentricity, no difference was found across ages in the effect of eccentricity. Similar findings have also been reported by Semenec, Buchler, Hoyer, and Cerella (2002) and Schieber and Benedetto (2001). Together, these studies suggest that spatial reduction in the scale of attention is similar for younger and older adults (as measured by accuracy of peripheral target detection; older adults have been shown to make more saccades to peripheral targets in difficult search conditions, although the results are more equivocal with regard to response time; see Scialfa, Thomas, & Joffe, 1994, and Scialfa & Joffe, 1997).

Finally, the predictive utility of the UFOV when administered to more general samples is uncertain. The levels of sensitivity and specificity in accident prediction reported by the creators of the UFOV have so far not been replicated in studies in which participants were not oversampled for accident frequency (Brown, Greaney, & Mitchel, 1993, as reported in Harris, 1999; Hennessey, 1995, as reported in Staplin et al., 1999).

Current Study

The current study was designed to address the issues described above by using a structural modeling approach. Using a simulated driving task and older drivers not deliberately sampled for severe visual impairments or previous accident history, we examined the contributions of UFOV test performance, a change detection task as an index of attentional search, age, and visual impairment in explaining variance in simulated driving performance. Despite the practical significance of accidents, the statistical burden of trying to predict such a rare occurrence limits the usefulness of accident history as an outcome measure, and self-censoring on the part of older drivers can limit the extent to which accidents occur. The range of driving difficulty can be extended further in simulated driving than in on-road testing, and thus simulator performance is likely to be a more sensitive measure of driving impairment than accident history. Because participants were not selected based on previous accident history as in other studies (e.g., Ball & Owsley, 1993), we expected accidents to occur rarely and, thus, to be unlikely to relate to individual differences in attention. We expected simulator performance to exhibit more differences across participants and thus to be more likely to relate to individual differences in visual impairment and visual attention than accidents.

A unique feature of this study is the use of DriverScan (Hoffman, Yang, Bovaird, & Embretson, 2005), a change detection task constructed using the methods of item response theory. Item response models create test scores that (a) are item-referenced instead of group-norm-referenced, (b) are directly comparable across different forms or occasions, and (c) incorporate differences in the psychometric properties or content across items. By considering these item differences, researchers can not only customize instruments to meet specific measurement goals but can empirically examine theoretical hypotheses regarding the cognitive processes or factors necessary for solving a given item. DriverScan items have been shown to be sufficiently unidimensional, reliable, and maximally sensitive to distinguishing individuals of lower attentional ability, as would be desired given the necessity of identifying persons with attention deficits when predicting driving impairment (Hoffman et al., 2005).

DriverScan presents real-world driving scenes in the flicker paradigm (Rensink, O'Regan, & Clark, 1997), and visual attentional search ability is indicated by the speed with which a single change made between repeated views of an otherwise identical scene is detected. In the flicker paradigm, original (A) and modified (A′) scenes are presented (200–400 ms) interspersed with blank screens of uniform luminance (60–100 ms): *A, blank, A, blank, A′, blank, A′, blank, A*. . .until the change is detected or a set amount of time has passed, whichever comes first. Including the blank screen eliminates local luminance cues that would normally signal the location of a change between scenes. Although Driver Scan is a laboratory task, it can be argued that search for change is highly applicable to real-world driving. The driver must monitor the environment for many types of important changes simultaneously, such as the color of an upcoming stoplight; the velocity of the vehicle ahead as well as the velocity of vehicles at other distances both in front, behind, and beside the car; merging vehicles; and unexpected pedestrians or objects in the roadway. Because the failure to note a change in any of these ongoing events could result in an accident, a measure of attentional search that features these types of scenarios may be a relevant predictor of driving impairment.

Considerable evidence indicates that visual attention is an integral part of successful change detection (Rensink, 2002; Rensink, O'Regan, & Clark, 2000; Turatto, Bettella, Umiltá, & Bridgeman, 2003) and operates similarly as in other visual search tasks (Rensink, 2000). Besides visual memory and scene perception, change detection tasks have also been used to explore both endogenous (i.e., goal-oriented) and exogenous (i.e., stimulus-driven) attentional processing. Changes are detected more quickly and accurately in semantically incongruent objects than congruent objects (Hollingsworth & Henderson, 2000) and in objects relevant to the observer's task than in those not as relevant to the task (Wallis & Bulthoff, 2000). Changes that alter the scene meaning are detected more quickly by experts than novices only when the scene context is expertise-relevant (Reingold, Charness, Pomplun, & Stampe, 2001; Werner & Thies, 2000), suggesting goal-directed factors may impact the shifting of attention when searching for change. Yet changes are also detected more quickly and accurately in exogenously cued objects than noncued objects (Scholl, 2000), as the number of changed object features increases (Smilek, Eastwood, & Merikle, 2000), and with increased size of the changed area (Williams & Simons, 2000), suggesting stimulus-driven attentional processes may play a role as well.

DriverScan was designed to incorporate both endogenous and exogenous factors that are likely to be relevant for measuring attentional search in older adults. First, scenes varied in their amount of visual clutter, or overall degree of congestion, given that declines in search rate are often found in the presence of many sources of competing information. Second, scene changes varied in their brightness, or overall conspicuity, given that declining visual functioning (e.g., contrast sensitivity) may reduce the quality of visual representations, which can impair subsequent attentional processing. Change salience has also been found to be an important factor in change detection speed for older adults in prior research (Pringle, Irwin, Kramer, & Atchley, 2001). Third, in order to reflect top-down attentional guidance, changes varied in their relevance to driving. In addition to its practical significance, driving provides a natural context in which certain objects and locations are preferentially selected for encoding, and the extent to which performance reflects this strategic component should be important in measuring attentional ability. Consistent with these expectations, DriverScan item difficulty has been shown to significantly relate to each feature, such that greater visual clutter, less change relevance, and less change brightness were related to greater item difficulty (Hoffman et al., 2005).

In this study, we assessed driving impairment through self-reported and state-recorded car accidents within the past 3 years, as well as performance in a driving simulator. The relations among age, visual impairment, visual attention, and driving impairment were evaluated in structural equation models in order to examine two hypotheses. First, we examined the contribution of a general factor of visual attention (i.e., as indicated by the UFOV and DriverScan scores) in predicting driving impairment, with the expectation that attention would predict driving impairment over and above the contributions of age and visual impairment, as has been shown in previous research (e.g., Ball & Owsley, 1993). Second, we examined the separate contributions of the UFOV and DriverScan in predicting driving impairment, with the expectation that the unique contributions of each would be significant.

Finally, the outcome of any potential screening instrument may ultimately come down to a dichotomous decision: Is a given person likely to be an impaired driver (or not)? Thus, the reliability with which the UFOV and DriverScan can identify impaired drivers was also examined using receiver operating characteristic (ROC) curves, in which the tradeoff between sensitivity (i.e., hit rate, or percentage of drivers correctly classified as impaired) and specificity (i.e., correct rejection, or percentage of drivers correctly classified as unimpaired) was evaluated for each measure across several cut points.

Method

Participants

A sample of 155 community-dwelling, currently licensed drivers from a Midwest metropolitan area was recruited by phone from an existing database of research participants. Participants received $30 as payment. The sample consisted of 68 men (44%) and 87 women (56%) between 63 and 87 years of age ($M = 75.2$, $SD = 4.7$). Most of the participants were White ($n = 149$, 96%) and the remainder, African American ($n = 6$, 4%). Of the 155 participants, 27 (17%) had completed high school or a General Educational Development degree only, 7 (5%) had an associate's degree, 66 (43%) had a bachelor's degree, 38 (25%) had a master's degree, and 17 (11%) had a Ph.D., J.D., M.D., or E.D. Participants rated their self-perceived physical health on a 6-point scale; 1 person (.6%) indicated *poor*; 10 (7%), *fair*; 61 (39%), *good*; 62 (40%), *very good*; and 21 (14%), *excellent*. Visual conditions reported included cataracts ($n = 19$, 12%), glaucoma ($n = 11$, 7%), macular degeneration ($n = 2$, 1%), or other retina-related problems ($n = 3$, 2%); some participants also reported undergoing cataracts/lens replacement surgery ($n = 23$, 15%) or laser surgery ($n = 2$, 1%). Visual acuity and contrast sensitivity information is provided in Table 1. Participants were relatively low-mileage drivers, reporting an average of 5.9 days per week ($SD = 1.5$, range = 1–7), covering an average of 102 miles per week ($SD = 86$, range = 5–600).

Simulator Apparatus

The driving task was completed in a fully interactive, fixed-base simulator (Model II, version 9, Systems Technology, Hawthorne, California) located in a windowless room and installed in a modified 1981 Dodge Aries with all interior controls and displays intact. The monitor was positioned on the hood of the car at a distance of 3.28 ft (1 m.) so that the 50° horizontal by 40° vertical visual angle display of the roadway scene and horizon was presented in the driver's line of sight. The responses of the car to the driver's actions had been designed according to the perceived motion of midsized cars of this type and size. Interactive components appropriate for a midsize vehicle included the following: steering wheel position and turn radius, throttle and acceleration, brake and deceleration, horn, and turn signals. All sampling was performed at 10 Hz; measures of performance analyzed in this study are described below. This simulator system has been used to examine driving behavior under various conditions, including under the influence of alcohol, Alzheimer's disease, and Parkinson's disease, has shown good correspondence to on-the-road performance, and has been subject to extensive research (e.g., Allen, Rosenthal, et al., 1998; Allen, Schwartz, Hogge, & Stein, 1979; Dubinsky, Schnierow, & Stein, 1992; Stein & Allen, 1987).

The driving course was a simulated two-lane highway that included segments of straight road (speed limits of either 55 or 65 mph), narrow-radius turns (40 mph), unmarked intersections, and stoplights. Warning signs signaled the occurrence of stoplights and unmarked intersections. In the unmarked intersections, cross-traffic was either absent, designed to allow the driver to avoid it if maintaining the current speed, or intended to result in a collision if the driver increased or decreased the current speed. Stoplights either remained green (i.e., must go), turned yellow 7 s before the driver reached the intersection (i.e., must stop), or turned yellow 3 s before the driver reached the intersection (i.e., could stop or go). Drivers also encountered stalled cars either in their lane or in the oncoming lane of traffic that needed to be passed in order to avoid an accident, often in the presence of a potentially overtaking car (i.e., the driver had to avoid passing while being passed), as well as pedestrians. Events were programmed as a function of the distance traveled; the timing of the stoplights, the presence of pedestrians, and cross-traffic were also dependent on the speed of the driver's vehicle.

Procedure

Participants were scheduled at the same time of day, 1 week apart, for each of two 60–90 min sessions if possible, and were allowed to wear any eyewear they felt would help them to perform the tasks optimally. In the first session, participants were given the measures of visual impairment, then given the UFOV and DriverScan in a dimly lit room, and finally, were asked to respond to the questionnaire.

Visual Impairment. For acuity at 10 ft. (3.05 m), participants read letters aloud on a Snellen chart binocularly, beginning with 20/50 vision,

Table 1
Frequency of Participants by Spatial Frequency at Each Contrast Level and at Each Acuity Level

Spatial frequency cycles/degree	Contrast sensitivity level[a] 0	1	2	3	4	5	6	7	8
1.5 c/d	0	3	7	12	20	35	70	120	170
n	0	0	0	4	18	84	46	0	0
3.0 c/d	0	4	9	15	24	44	85	170	220
n	0	0	1	2	15	84	50	0	0
6.0 c/d	0	5	11	21	45	70	125	185	260
n	0	2	7	24	87	28	4	0	0
12.0 c/d	0	5	8	15	32	55	88	125	170
n	10	14	57	59	7	2	3	0	0
18.0 c/d	0	4	7	10	15	26	40	65	90
n	47	36	44	19	2	4	0	0	0

Distance	Acuity level 20/60	20/50	20/40	20/30	20/25	20/20
10 ft	20/60	20/50	20/40	20/30	20/25	20/20
n	1	7	33	35	50	26

[a] The highest contrast level answered correctly was recorded at each spatial frequency. The values given on each spatial frequency row indicate the exact contrast levels examined within that spatial frequency, where higher contrast levels indicate greater contrast sensitivity. The number of participants who scored at each contrast level is then reported per spatial frequency. The number of participants who scored at each level of acuity at 10 ft. is also reported.

and continuing through 20/40, 20/30, 20/25, and 20/20. The smallest line of letters read correctly was recorded. For contrast sensitivity (assessed monocularly at 10 ft. with the VisTech 6500 Contrast Sensitivity Chart; Vistech Consultants, Dayton, Ohio), participants made a three-alternative choice as to the orientation of lines varying in five spatial frequencies (1.5, 3, 6, 12, or 18 cycles/degree) and eight contrast levels within each frequency (see Table 1). The lowest contrast level answered correctly for each frequency was recorded.

UFOV. Participants were seated 24 in. (60.96 cm) away from a 17-inch CRT monitor (approximately 40° visual angle). Participants had to answer three of the four practice trials correctly before beginning. For the processing speed subtest, a central target (3 × 5° visual angle) was initially presented for 240 ms, after which a random noise mask was displayed. A forced-choice discrimination (car or truck) was then made via mouse input (response time was not recorded). Central target duration was decreased after two correct responses, and duration was increased after each incorrect response. The increase or decrease ranged from 17 to 50 ms, depending on the number of errors in the previous trials, to a maximum of 332 ms and a minimum of 17 ms. Testing continued until the threshold of 75% correct was reached, as determined by the geometric mean of the stimulus durations for five consecutive correct-incorrect reversals. For the divided attention subtest, participants performed the central discrimination task and then also indicated along which of eight spokes a peripheral target (a car also subtending 3 × 5 ° visual angle) was located. This subtest began with a stimulus duration of 160 ms if the minimum duration determined in process speed was 40 ms or less; it was 200 ms for minimum duration in process speed of 41–80 ms; and 240 ms for minimum duration in process speed of 80 ms. Stimulus duration was increased or decreased by 40-ms increments, to a maximum of 240 ms or a minimum of 40 ms. The selective attention subtest was similar to that of divided attention, except that the peripheral task was performed in the presence of 47 triangles located randomly across the 30° visual field. In each subtest, the central discrimination task had to be correct for the trial to be scored.

DriverScan. Participants were seated 30 in. (76.20 cm) away from a 17-inch LCD monitor (approximately 24° visual angle) and were told they would be viewing photographs of real-world driving scenes with a single change made between successive presentations (changes included object deletions, color changes, and lettering changes). Items varied in their visual clutter (i.e., the overall degree of scene congestion,) brightness of the change (i.e., physical salience or conspicuity of the change), and relevance of the change to driving (i.e., whether the change would be meaningful to the driver), as rated independently by older adults. High relevance changes included changes to stoplights, pedestrians, construction markers, turn signals, road or street signs, and elimination of nearby cars. Low relevance changes included changes to logos on pedestrians or cars, billboards, light poles, buildings, trees, and relatively distant cars. Participants were instructed to find the change as quickly as possible and to respond with the left mouse button and orally report the change to the experimenter. Photographs (original–*A*, altered– *A′*) were presented for 280 ms with blank screens presented for 80 ms in the sequence *A, blank, A, blank, A′, blank, A′, blank* for 45 s or until the participant responded, whichever occurred first. After viewing an example and completing eight practice trials, participants were administered 38 items in a random order. E-prime software (Psychology Software Tools, Pittsburgh, PA) was used to present the items and record response times. Attentional abilities were estimated ($M = 0$, $SD = 1$) in a constrained graded response model for outcomes of 0 = *no response* (> 45 s.), 1 = *delayed response* (8–45 s.), and 2 = *immediate response* (< 8 s.). See Hoffman et al. (2005) for more details.

Simulated driving. During the second session, participants completed the simulated driving task. The experimenter first completed an example drive illustrating various aspects of the course. Participants then completed seven training drives in which mastery of the focus of each training drive needed to be demonstrated before continuing, with participants resting briefly (< 5 min) between drives as needed. The first drive featured a 12,000 foot road (speed limit, 55 mph) with straight segments and easy curves. The second drive featured a 6,600-ft (2,011.68-m) straight road (with no posted speed limit) to introduce participants to the divided attention task, the stimuli for which appeared in the upper left- and right-hand corners of the monitor. Separate cues informed the participants to honk the horn (a horn sign on either side of the monitor), signal for a left turn (a triangle on the left side), or signal for a right turn (a triangle on the right side), each presented until a response was detected or for a maximum of 5 s. A diamond sign, a neutral cue to which the participants should not respond, was otherwise present in the stimuli locations. The third drive was an 11,000-ft (3,352.80-m) straight road (speed limit, 65 mph) in which participants passed slowly moving cars in the right lane; oncoming traffic was present half the time, although there was sufficient time to pass. The fourth drive was a 10,000-ft. (3,048.00-m) straight road (speed limit, 65 mph) that included unmarked intersections and stoplights. The fifth drive was a 10,000-ft (3,048.00-m) straight road (no posted speed limit) in which the participant learned to negotiate a double-lane change (i.e., must pass between three cars in the left and right lanes). The sixth drive was a 10,000-ft (3,048.00-m) road with narrow turns (speed limit, 40 mph). Finally, the seventh drive was a 14,000-ft (4,267.20-m) straight road (speed limit, 65 mph) in which participants passed slowly moving vehicles in the presence of an overtaking car (also presented in the top left corner of the monitor).

Participants were given a chance to rest for as long as needed (5–10 min) before beginning the test course and were then reminded of all course obstacles and encouraged to drive as quickly as they could safely, obeying all posted speed limits and traffic lights. The course covered a total distance of 71,500 ft. (217.93 km), took approximately 20–25 min to complete, and featured all of the scenarios described previously, as well as two “surprise” vehicles (i.e., vehicles appearing suddenly in front of the participant’s vehicle) and two airplanes bearing advertisements flew across the screen. Within the test course there were two 4,000 ft. (1,219.20-cm) segments of straight road with two oncoming cars; the eight divided attention tasks were presented during one of these segments. Two other divided attention trials occurred during other segments of the course. As with the rest of the course obstacles, the divided attention trials were presented in the same order and at the same course distance for each participant. Course performance was assessed via six measures: crashes (frequency of collisions with other vehicles, off-road accidents, and collisions with pedestrians, each signaled via a loud crashing noise and a cracked windshield), number of stoplight violations (i.e., when the driver ran a red light, each signaled with a siren), number of speeding violations (3 mph or more than speed limit; 30% signaled with a siren), lane position variation in the divided attention segment (measured in root-mean-square error, or RMS), proportion of missed divided attention tasks, and overall drive time.

Accident history. Participants were also asked to report details of any accidents that had occurred during the preceding 3 years with other drivers or property (e.g., parked cars, mailboxes), including whether or not the police were called and the participants’ perceptions of fault (*not at all*, *partially*, or *fully my fault*). On completion of the study, participants were given the opportunity to sign permission forms for the experimenter to access to their state recorded driving histories from the past 3 years; 95% of participants ($n = 147$) granted permission. Copies of the signed permission forms were mailed to the relevant state bureaus, and copies of any accident reports held by the state or local police departments involving consenting participants were then sent to the experimenter. A total of 38 accidents involving 34 participants were referenced either by participants and/or through state records. Accidents were coded by two experimenters as *no fault*, *partially at fault*, or *fully at fault* using the participants’ descriptions and any available accident records. The proportion of agreement between the participants’ descriptions and the accident records was 35 of 38 (92%); discrepancies were resolved case-by-case. Of the 26 accidents involving 21 participants classified as a participant being at least partially at fault, only 1 was not reported by the participant. The police

Table 2
Latent Variable Correlations

Variable	Age	VI	UFOV PS	VA	UFOV DA	UFOV SA	DS	DI
Age	—	**0.22**	0.11	**0.46**	**0.28**	**0.31**	**0.40**	**0.33**
Visual Impairment (VI)		—	0.18	**0.30**	0.15	**0.27**	**0.23**	0.10
UFOV processing speed (UFOV PS)			—	**0.27**	**0.20**	**0.22**	**0.19**	**0.34**
Visual attention (VA)				—	n/a	n/a	n/a	**0.71**
UFOV divided attention (DA)					—	**0.52**	**0.50**	**0.53**
UFOV selective attention (SA)						—	**0.57**	**0.41**
DriverScan							—	**0.60**
Driving Impairment (DI)								—

Note. Significant correlations ($p < .05$) are printed in **bold.** UFOV = Useful Field of View Test.

were not called to the scene for 13 accidents (e.g., only minor property damage). Only 5 of the remaining 13 accidents for which the police were called were referenced by the state, however. Thus, self-reports identified 92% of the accidents for which the police were called, whereas state records identified 38% of the accidents for which the police were called.

Results

All measures were scored such that greater values (i.e., more positive or less negative values) indicate greater impairment. Contrast sensitivity was the highest contrast sensitivity for each spatial frequency (multiplied by −1), and far acuity was the denominator for the acuity ratio of the last line answered correctly (e.g., 20/40 would be 40) of a possible 20/20. UFOV scores were the threshold given for each subtest, and the DriverScan scores were ability estimates (multiplied by −1). Some participants were unable to complete the driving simulator task due to malfunction ($n = 5$) or discomfort ($n = 15$); full information maximum likelihood (FIML) estimation was used under the assumption of missing at random (i.e., that data are missing at random after accounting for model variables). Simulator measures included lane position variability (RMS in feet), proportion of missed divided attention tasks, frequency of crashes, stoplight violations, and speeding violations, and course time in minutes. Accident history was scored 0 for no at least partially at-fault accidents in the past 3 years and 1 otherwise. The contrast sensitivities, UFOV subtests, and simulator measures of lane position variability, proportion of missed divided attention tasks, number of crashes, and course time were log-transformed to improve multivariate normality, an assumption required for endogenous variables in structural models. On graphical and statistical inspection, we identified three multivariate outliers with extreme values[1] on the vision and attention measures. These cases were removed from the following analyses so that they would not have undue influence on the solution.

Correlations, means, and standard deviations for the sample ($n = 152$) are given above the diagonal in the Appendix. Correlations among UFOV divided attention, UFOV selective attention, and DriverScan ranged from .5 to .6, indicating that these measures shared a common attentional component, but their correlations with UFOV processing speed were approximately .2, indicating that processing speed appeared to assess a different construct. As a result of both theoretical and empirical considerations, UFOV processing speed served as a single infallible indicator of its own construct in each model.

Measurement Models

All models were estimated using FIML in Mplus 3.0 (Muthén & Muthén, 1998–2004). Likelihood ratio tests (χ^2), confirmatory fit indices (CFI), and root mean square error of approximation (RMSEA) were used to assess model fit. CFI is in index of goodness of fit, where higher values indicate better model fit. RMSEA is an index of badness of fit, where lower values indicate better model fit. Measurement models for the factors with more than three indicators (i.e., that were overidentified) were examined first in order to ensure acceptable unidimensionality of each factor before examination of the structural relationships. A one-factor model of Visual Impairment with indicators of the five contrast sensitivities and far acuity had marginal fit, $\chi^2(9, N = 152) = 17$, $p = .04$, CFI = .97, RMSEA = .08. A one-factor model of Simulator Driving Impairment with six indicators fit poorly, $\chi^2(9, N = 132) = 44$, $p < .001$, CFI = .48, RMSEA = .17. However, because course time and speeding violations are independently related, a residual correlation was added between these indicators, resulting in acceptable model fit, $\chi^2(8, N = 152) = 13$, $p = .12$, CFI = .93, RMSEA = .07.

Structural Models

Simulator performance. The first structural model examined included latent factors of visual impairment, general visual attention deficits, and simulator driving impairment and measured variables for age and processing speed. Correlations among the latent constructs are shown in Table 2. Latent factors of visual impairment and simulator driving impairment were estimated as described previously, and general visual attention deficits were indicated by the UFOV divided and selective attention subtests and by DriverScan. This model, as shown in Figure 1, had acceptable fit, $\chi^2(113, N = 152) = 147$, $p = .02$, CFI = .94, RMSEA = .05,

[1] Multiple regression of the factor scores for the visual impairment indicators, factor scores for visual attention indicators, and a *z*-scored processing speed measure was used to estimate Cook's leverage values. Leverages greater than .05 were identified as potentially problematic, as calculated from $2p/N$, where p = the number of parameters (Kutner, Nachtsheim, Neter, & Li, 2004, p. 398). Because this criterion can be overly sensitive, we identified cases above this criterion as multivariate outliers only if their leverage values were clearly distinct from those in the rest of the sample (in this case, above .09).

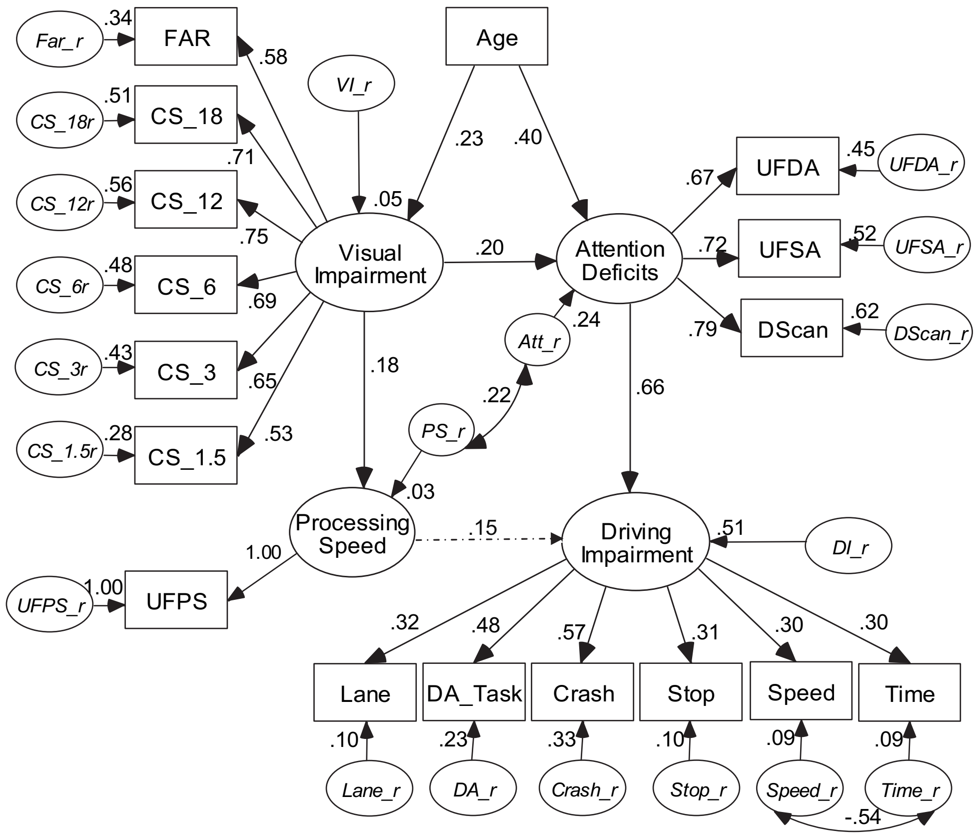

Figure 1. Structural model predicting simulator driving impairment from latent factors of visual impairment, Useful Field of View processing speed, and attention deficits. Dotted lines indicate nonsignificant path estimates. FAR = static distance acuity, CS = contrast sensitivity at cycle/degree specified, VI = Visual Impairment factor, Att = Attention factor, PS = processing speed subtest, UFDA = Useful Field of View test (UFOV) divided attention, UFSA = UFOV selective attention, DScan = DriverScan. UFPS = UFOV processing speed, DI = Driving Impairment, Lane = lane position variability, DA task = missed divided attention tasks, Crash = no. of crashes, Stop = stoplight violations, Speed = no. of times speeding, Time = course time, _r = residual variances.

and accounted for 51% of the variance in simulator driving impairment. Age had a significant direct effect on visual impairment and general attention deficits, and visual impairment had a significant direct effect on general attention deficits and marginally significant direct effect on processing speed. A significant residual correlation was observed between processing speed and general attention deficits. General attention deficits had a significant direct effect on driving impairment, whereas processing speed did not, as indicated by the dotted lines in Figure 1.

The unique contribution of each attention measure in predicting simulator driving impairment was examined next. Correlations are shown in Table 2. This model had acceptable fit, $\chi^2(108, N = 152) = 142$, $p = .02$, CFI = .94, RMSEA = .05, and accounted for 44% of the variance in driving impairment. As shown in Figure 2, Age had a significant direct effect on visual impairment and each of the attention measures. Visual impairment had significant direct effects on processing speed and selective attention but not on divided attention and DriverScan, as indicated by dotted lines in Figure 2. Significant residual correlations were observed between the attention measures. Finally, DriverScan had a significant direct effect on simulator driving impairment, divided attention had a marginally significant direct effect on simulator driving impairment, and the direct effects of processing speed and selective attention were not significant, also indicated by dotted lines in Figure 2. After removing all nonsignificant paths (not shown), model fit remained acceptable, $\chi^2(112, N = 152) = 153$, $p = .01$, CFI = .93, RMSEA = .05. Divided attention and DriverScan accounted for 42% of the variance in driving impairment, with standardized paths of .29 and .46, respectively.

Finally, the extent to which the UFOV subtests and driverScan could predict by themselves simulator driving impairment was examined in separate models for each measure (not shown). In the UFOV model, age predicted visual impairment and the subtests of divided attention and selective attention. Visual impairment predicted each subtest, and residual correlations were estimated among the subtests. The UFOV model had acceptable fit, $\chi^2(95, N = 152) = 129$, $p = .01$, CFI = .93, RMSEA = .05. UFOV processing speed, divided attention, and selective attention accounted for 34% of the variance in driving impairment, with standardized paths of .22, .37, and .18, respectively, although only

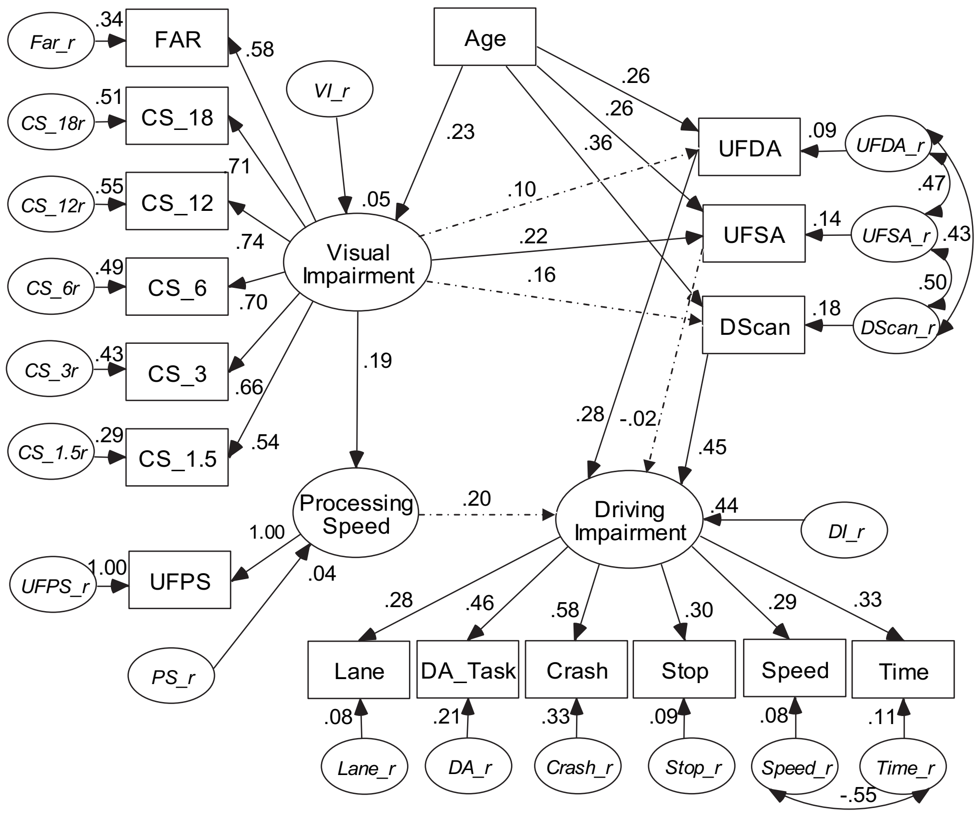

Figure 2. Structural model predicting Simulator Driving Impairment from latent factors of Visual Impairment, Useful Field of View (UFOV) processing speed, and separate measures of Attention (UFOV divided Attention, UFOV selective attention, and DriverScan attentional shifting). Dotted lines indicate nonsignificant path estimates. FAR = static distance acuity, CS = contrast sensitivity at cycle/degree specified, VI = Visual Impairment factor, Att = Attention factor, PS = processing speed subtest, UFDA = Useful Field of View test (UFOV) divided attention, UFSA = UFOV selective attention, DScan = DriverScan. UFPS = UFOV processing speed, DI = Driving Impairment, Lane = lane position variability, DA task = missed divided attention tasks, Crash = no. of crashes, Stop = stoplight violations, Speed = no. of times speeding, Time = course time, _r = residual variances.

the direct effect of divided attention was not significant. In the DriverScan model, age could be used to predict visual impairment and DriverScan, visual impairment could be used to predict DriverScan, and DriverScan alone could be used to predict simulator driving impairment. The DriverScan model also had acceptable fit, $\chi^2(74, N = 152) = 102$, $p = .02$, CFI = .93, RMSEA = .05, and accounted for 36% of the variance in driving impairment (significant direct effect of .60).

Accident history. As expected given that accident history was not correlated with any variable, no structural models could account for more than 2% of the variance in accident history.

Reliability of Risk Prediction Across Instruments

The extent to which the UFOV subtests and DriverScan could identify whether or not a given participant was likely to be an impaired driver was examined using ROC curves. Accident history was used as one indicator of impairment ($n = 21/152$). Although no such clear-cut distinction was available for simulator performance, a continuous measure, we operationalized impaired performance as a simulator factor in the lowest quartile ($n = 30/132$). The tradeoff between sensitivity (i.e., hit rate) and specificity (i.e., correct rejections) for identifying impaired drivers was evaluated for each attention measure across several potential cut points. In order to make comparisons with previous research, UFOV cut points were derived from the risk scores computed from the combination of thresholds obtained across subtests, as suggested in the UFOV manual: 65 were considered as 1, *very low risk*; 44 as 2, *low risk*; 32 as 3, *low to moderate risk*; 9 as 4, *moderate to high risk*; and 2 as 5, *high risk*. In DriverScan, cut points were deficits greater than .00, .50, 1.0, or 1.50. Finally, classification was also examined as made by either measure or both measures. The number of participants labeled as "impaired" at each cut point for each measure is given in Table 3.

In the ROC plots, the further to the left of the diagonal the curves are, the more accurate the measure is. ROC curves for accident history are shown in the top of Figure 3. Neither measure did noticeably better than chance. The most liberal cut point resulted in a 40% true- and a 45% false-positive rate for Driver-

Table 3
Participants Classified as At Risk for Driving Impairment by Measure and Cut Point

Measure and cut point	Accidents (n = 152) N	Accidents %	Simulator (n = 132) N	Simulator %
DriverScan				
Deficits > .00	68	44.7	58	43.9
Deficits > .50	47	30.9	40	30.3
Deficits > 1.00	26	17.1	21	15.9
Deficits > 1.50	10	6.6	8	6.1
UFOV				
Risk > 1	87	57.2	56	42.4
Risk > 2	43	28.3	37	28.0
Risk > 3	11	7.2	10	7.6
Risk > 4	2	1.3	2	1.5
DriverScan or UFOV				
Deficits > .00 or Risk > 1	97	63.8	83	62.9
Deficits > .50 or Risk > 2	68	44.7	57	43.2
Deficits > 1.00 or Risk > 3	30	19.7	24	18.2
Deficits > 1.50 or Risk > 4	11	7.2	9	6.8
DriverScan and UFOV				
Deficits > .00 and Risk > 1	58	38.2	51	38.6
Deficits > .50 and Risk > 2	22	14.5	20	15.2
Deficits > 1.00 and Risk > 3	7	4.6	7	5.3
Deficits > 1.50 and Risk > 4	1	0.7	1	0.8

Note. UFOV = Useful Field of View.

Scan and a 60% true- and a 57% false-positive rate for UFOV. The most liberal cut point for either measure led to a 60% true- and a 64% false-positive rate; both measures lead to a 40% true- and 38% false-positive rate. ROC curves for simulator impairment are shown in the bottom of Figure 3. The measures fared noticeably better for predicting simulator Driving Impairment than for predicting accidents. For DriverScan, the best sensitivity rate was 71%, at a cost of 35% false-positives. For UFOV, the best sensitivity rate was 85%, at a cost of 48% false-positives. The most liberal cut point by either measure led to a 88% true- and a 54% false-positive rate; both measures lead to a 68% true- and 29% false-positive rate.

Discussion

Summary of Findings

The goal of the current study was to explore the role of different aspects of visual attention in predicting driving impairment in older adults, expanding upon previous work in three notable ways. First, participants were not oversampled for accident frequency or greater visual impairment as in other studies (e.g., Ball & Owsley, 1993), so that prediction of Driving Impairment could be evaluated in a sample whose results were more likely to be able to be generalized to the overall population of older adults. Second, we included a newly constructed measure (DriverScan) along with an existing measure of visual attention (UFOV). Third, we used both recent real-world accidents and simulator driving performance as outcomes.

Structural modeling was used to examine the relations among age, visual impairment, UFOV and DriverScan performance, and Driving Impairment as indicated by six simulator measures. We chose to model UFOV processing speed as a separate construct and included residual correlations with the attention measures where needed. Because the UFOV divided and selective attention subtests and DriverScan each required some attentional processing and had considerable shared variance, we modeled them as a general latent factor of attentional deficits, yet also considered the unique contributions of each measure in additional models.

Age directly predicted visual impairment and general attention deficits and was also indirectly related to processing speed and attention through visual impairment. That direct effects of age on attention general/deficits remain after accounting for visual impairment suggests that increasing age is accompanied by specific cognitive deficits in addition to sensory or perceptual deficits that affect the quality of visual representations. That a direct effect of age on processing speed was *not* found after accounting for visual impairment suggests that little complex processing is involved in performing the UFOV central discrimination task by itself. Finally, no direct impact of age or visual impairment on simulator driving impairment was found after accounting for deficits in processing speed and attention, suggesting that these higher order processes are more likely to be related to impairment in older drivers, rather than more basic sensory visual processes.

The role of attention in predicting simulator driving impairment was considered in three sets of models to examine two hypotheses.

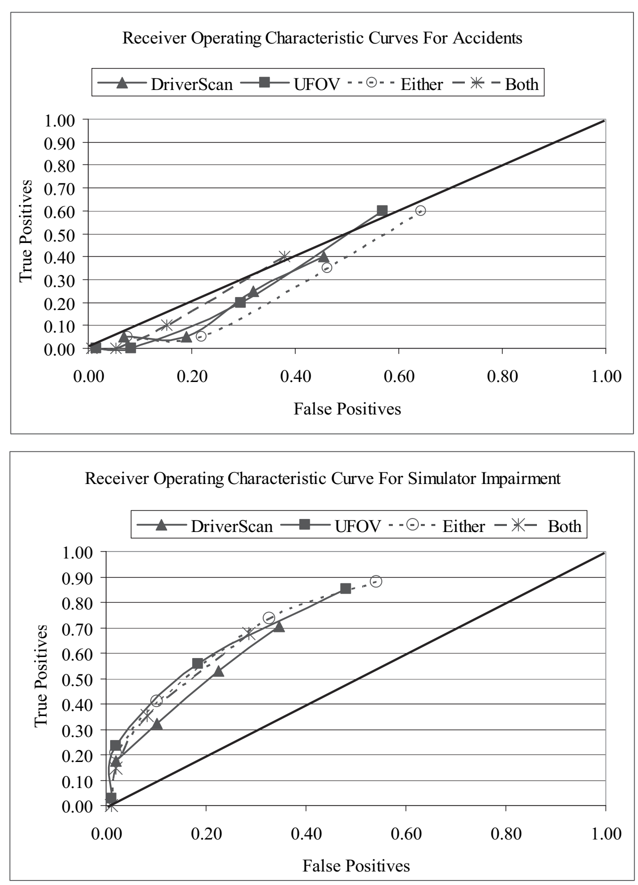

Figure 3. Receiver operating characteristic curves predicting accident history (top panel) and simulator driving impairment (bottom panel) from Useful Field of View Test (UFOV) and DriverScan.

First, as hypothesized, the latent factor of general attention deficits was a significant predictor of simulator driving impairment after controlling for age, visual impairment, and processing speed. Processing speed was not a significant predictor of simulator driving impairment after controlling for general attention deficits. Next, we examined the unique contributions of each measure in predicting simulator driving impairment. As hypothesized, significant unique effects were found for DriverScan and for UFOV divided attention. Contrary to what was expected, the unique contributions of UFOV selective attention and processing speed did not remain significant. Finally, the UFOV subtests and DriverScan accounted for 34% and 36% of the variance in simulator driving impairment, respectively, as evaluated in separate structural models for each measure.

Together, these results suggest that DriverScan and the UFOV divided and selective attention subtests assess related but separate aspects of attention. Although they shared sufficient variance with which to form a latent factor (which could be used to predict simulator driving impairment), unique contributions in predicting simulator driving impairment were also obtained when modeling the instruments separately, possibly reflecting specific attentional and cognitive components measured by each task. For example, in the DriverScan change detection task, as in other visual search tasks, some degree of working memory and executive control must be used to remember which objects or locations have already been searched and to deliberately avoid revisiting those areas. Consistent with this notion, Pringle, Kramer, and Irwin (2004) reported that a composite measure of visuospatial working memory was the strongest correlate of change detection response time in a battery of cognitive tests administered to older and younger adults ($r = -.78$, although the correlation may have been inflated by the mean differences between the age groups). Further work is needed to identify the specific processes underlying change detection performance that may experience age-related decline.

On examining the contribution of each attention measure simultaneously, we found that DriverScan was the strongest predictor of simulator driving impairment. Why might this be the case? One hypothesis is that the UFOV is not sensitive enough to reflect impairments present in a healthier sample such as that used in this study. A more sensitive measure would have been more strongly related to simulator driving impairment, thus capturing more variance, and reducing the unique contribution of DriverScan. However, sensitivity may not be the issue, given that Pringle et al. (2004) reported a correlation comparable to that observed in the current study between change detection response time and functional field of view size (i.e., a UFOV-like task in which the eccentricity of peripheral targets varies instead of presentation time). Yet because no driving measures were included in Pringle et al., the possibility of a null result arising from a lack of sensitivity of the UFOV in measuring attentional scaling cannot be ruled out.

Another hypothesis relates to the influence of context. DriverScan uses real-world driving scenes, providing a natural context in which to organize attentional selection and search strategies. Participants did appear to be responding to the context, in that changes of high relevance to driving were easier to detect than changes of low relevance (Hoffman et al., 2005). No such contextual background is used in the UFOV, and thus the attentional selection process is more artificial. As a result, older adults who can effectively use context to guide their attention in everyday life might be at a disadvantage when completing the UFOV, which could lead to the conclusion that older adults whose selective attention abilities are enhanced by context are more impaired than they actually are. Finally, because the DriverScan items also vary in the amount of visual clutter in the scene and the brightness of the change, DriverScan may allow for a more sensitive determination of the extent to which attentional processes are compromised by perceptual factors in different individuals (i.e., as a result of the amount of competing information in the scene or the salience needed for the change to be noticeable).

In the UFOV processing speed subtest, no attentional scaling or filtering is needed—an isolated target is always presented centrally. It is thus unlikely that any appreciable degree of attentional processing is required. In contrast, the UFOV divided and selective attention subtests do require distribution of attention, because observers must respond to two spatially separated targets within the time limit. The relative potency of the attentional gradient appears to be evaluated only in the selective attention subtest, however, in which peripheral targets do not "pop-out" and instead must be located among distractors. Yet UFOV selective attention did not reliably predict Driving Impairment when modeled with the other UFOV subtests, even though its task requirements should render it the most sensitive of the UFOV subtests to any attentional scaling deficits. The differential predictive relationships with simulator Driving Impairment across subtests in combination with the differential task requirements and the lack of correlation found between the processing speed subtest and the other subtests together suggest that forming a unidimensional composite of the UFOV subtests does not appear justified.

Limitations

There are several limitations to the current study. One concerns the extent to which performance in the driving simulator can be generalized to on-road performance, given the artificial nature of the task (i.e., limited visual environment, no motion feedback). To minimize any effects of task novelty, however, we had the participants complete several training drives and did not allow them to start the final course until they achieved mastery on each of the necessary skills. Because obvious safety risks preclude placing older adults in difficult driving situations in a real car, simulated driving is one way in which people's responses to more challenging situations can be evaluated without real-world consequences. The course used in the current study was difficult to navigate; only 4% of the sample missed no divided attention tasks while driving, suggesting that the driving task was highly engaging. Further, only 23% had no crashes on the course. The relative difficulty of the course combined with the relative unfamiliarity of the vehicle controls may have allowed us to witness deficits in our participants that otherwise would not have been visible in standard driving conditions, but more work is needed to evaluate the extent to which these deficits indicate real driving problems.

Another limitation concerns the practical utility of the attention measures investigated in the current study with regard to identifying potentially impaired drivers. Accident history was not related to any other variable, including the UFOV, and the sensitivity and specificity of the UFOV and DriverScan in identifying persons who had had a recent accident were abysmal (i.e., true-positives increased at the same rate as false-positives). This finding stands in sharp contrast with previous reports, in which the UFOV accounted for 20–25% of the variance in accident frequency. The frequency of state-recorded accidents obtained in the current sample (3.2%) was comparable to the proportion of licensed drivers who had had an accident during the year of study in the participants' state of residence (3.0%), suggesting the current sample was more representative of the general public with regard to driving impairment than samples used in previous research. (i.e., 50% and 67% of participants had been involved in a recent accident in Owsley et al., 1991, and Ball & Owsley, 1993). Similarly, the current sample had substantially less visual and attentional impairment than those in previous research (i.e., 51% and 57% of participants failed the UFOV in the studies conducted by Owsley et al., 1991, and Ball & Owsley, 1993; under the same criteria, 0% or 25% of current participants would have failed). With Brown et al. (1993, as reported in Harris, 1999) and Hennessey (1995, as reported in Staplin et al., 1999), the UFOV did not predict accident history in the current study when participants were not oversampled for visual impairment or accident risk.

Sensitivity and specificity levels of UFOV and DriverScan in identifying participants impaired on simulator performance (i.e., "impaired" drivers) were somewhat better, although still mediocre at best. This finding is somewhat surprising given that these tests accounted for almost half of the variance in a latent factor of simulator driving impairment in structural models. However, the challenges in analyses such as these are great. For example, although incredibly important in terms of practical applications, the distinction made between impaired and unimpaired simulator performance required by the ROC analyses was admittedly arbitrary and would be difficult to validate in this relatively unimpaired and low-accident sample (i.e., adequate sensitivity was achieved only by designating over 60% of the sample as "at risk").

Nonetheless, the push to develop measures that can increase safety on our roads continues to be present. In addition to safety concerns, there are social and personal costs associated with this initiative. The goal of this line of research is to identify measures that adequately balance safety (i.e., sufficient sensitivity to identify impaired drivers) with personal autonomy (i.e., sufficient specificity not to misidentify unimpaired drivers as impaired). Although the analyses reported here indicate that at present that neither the UFOV test nor DriverScan can be used to reliably identify older adults who are at risk for driving impairment, these instruments could be used as preliminary screening tools to flag those individuals whose visual attention processing deficits are severe enough to warrant further testing. Additional research involving older adults with a broader range of visual and attentional abilities is required to further develop measures to address the needs of both society and the individual in the context of driving safety.

Conclusion

Although deficits in visual attention are often postulated as an important component of many declines in cognitive processing and functional outcomes in older adults, surprisingly little emphasis has been placed on the evaluation of psychometric instruments with which individual differences in visual attention abilities can be assessed. In exploring the relationships among different measures of attention in the current study, as well as their utility in predicting driving impairment in older adults, we hope to encourage further development in this area.

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(*Appendix follows*)

Appendix

Bivariate Correlations, Mean, and Standard Deviations for the Study Variables

	Predictors											Driving impairment outcomes						
Variable	Age	CS (1.5)	CS (3)	CS (6)	CS (12)	CS (18)	Acuity	UFOV PS	UFOV DA	UFOV SA	DS	Lane	DA task	Crash	Stop-lights	Speed	Time	Acc
Age		−0.01	0.09	0.12	0.20	**0.22**	**0.23**	0.11	**0.28**	**0.31**	**0.40**	0.13	**0.23**	0.06	0.03	0.16	0.15	0.05
Contrast sensitivity *-1 (1.5 c/d)[a]			**0.52**	**0.37**	**0.36**	**0.34**	**0.27**	0.12	0.01	0.11	−0.01	−0.03	0.18	0.06	0.01	−0.05	−0.04	0.02
Contrast sensitivity *-1 (3 c/d)[a]				**0.47**	**0.47**	**0.43**	**0.32**	**0.18**	0.01	0.19	0.18	0.04	0.10	0.07	0.13	−0.01	−0.04	−0.09
Contrast sensitivity *-1 (6 c/d)[a]					**0.52**	**0.48**	**0.99**	0.24	0.16	**0.24**	0.17	0.10	0.09	−0.04	0.10	0.09	−0.03	0.03
Contrast sensitivity *-1 (12 c/d)[a]						**0.57**	**0.45**	0.04	0.12	0.13	0.15	0.12	0.16	−0.01	0.01	0.09	−0.06	−0.04
Contrast sensitivity *-1 (18 c/d)[a]							**0.46**	0.09	0.11	0.18	0.16	0.08	0.13	−0.09	0.04	0.00	−0.18	0.06
Static distance acuity								0.07	0.19	**0.23**	**0.25**	0.05	0.14	0.15	0.09	0.15	−0.03	−0.01
UFOV processing speed[a]									0.19	**0.22**	0.19	0.05	0.17	0.17	0.06	0.04	**0.24**	−0.05
UFOV divided attention[a]										**0.52**	**0.50**	0.13	0.21	**0.30**	0.11	0.12	**0.28**	0.02
UFOV selective attention[a]											**0.57**	**0.29**	0.18	**0.25**	0.16	0.09	0.13	0.09
DriverScan *-1												0.20	**0.23**	**0.35**	**0.27**	0.14	**0.23**	0.00
Lane position variability[a]													0.11	**0.25**	0.19	0.16	−0.08	−0.07
Missed divided attention tasks[a]														**0.28**	0.19	0.09	**0.26**	−0.09
No. of crashes[a]															0.21	**0.26**	0.09	−0.12
No. of stoplight violations																0.06	0.01	−0.10
No. of times speeding																	**−0.40**	−0.03
Course time[a]																		−0.05
Real-life accident (0 = no, 1 = yes)																		
M (*N* = 152)	75.10	−3.70	−3.94	−3.73	−2.37	−1.41	30.26	2.80	4.35	5.58	−0.01	0.82	0.26	0.86	0.20	8.36	3.15	0.13
SD (*N* = 152)	4.58	0.44	0.43	0.53	0.81	1.00	8.29	0.50	0.98	0.45	1.00	0.18	0.15	0.61	0.44	4.90	0.10	0.34

Note. Significant correlations ($p < .01$) are printed in **bold.** CS = Contrast Sensitivity, UFOV = Useful Field of View Test, DA = Divided attention, SA = Selective attention, DS = DriverScan, Acc = Accident.
[a] Log-transformed to normality.

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