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Development of peripheral vision tests for driver assessment

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ABSTRACT

In the interests of identifying older drivers at higher risk of crashing, with a view to restricting their driving, fitness to drive tests require development and validation. One particular test that makes claim for inclusion in any battery of fitness to drive tests is the Useful Field of View test (UFOV)[1]. UFOV subtests appear to depend heavily on speed of visual processing, and on indexing crowding in peripheral vision. However, UFOV is a proprietary instrument and other custom software is available for measuring speed of visual processing and crowding in peripheral vision. Sixty participants aged over 60 completed UFOV. They also completed inspection time (IT), a measure of speed of visual processing, and crowding across the visual field (CAVF), a measure indexing effects of strength of crowding in peripheral vision. Thus, the current study compared performance on UFOV, inspection time (IT) and crowding across the visual field (CAVF). The main outcomes here were that the IT and CAVF measures had high test-retest reliability over a period of about one week and did not exhibit statistically significant practice effects. By way of contrast, although UFOV measures were also highly reliable, two of three UFOV measures, Divided Attention and Selective Attention, showed practice effects; the third measure, Processing Speed, showed severe range restriction in the current sample of healthy older adults. Correlations between CAVF, IT and UFOV Selective Attention were very high. These outcomes suggests that IT and CAVF together may well prove appropriate and useful as part of an assessment of fitness to drive. This suggestion needs to be validated by research investigating whether these tests predict crash risk in the same way that UFOV does.

KEYWORDS

Visual field, Fitness to drive, Aged driver

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[1] UFOV®is a registered trademark of Visual Awareness, Inc., Chicago, IL

Summary

The rationale for the current study has the following elements. Older drivers are over-represented in at-fault crashes. These crashes display a unique profile that is consistent with the involvement of deficits in performance at perceptual, motor, and higher cognitive levels, with particular emphasis on speed of information processing deficits. Therefore, in the interests of identifying older drivers at higher risk of crashing, with a view to restricting their driving, fitness to drive tests require development and validation. One particular test that makes claim for inclusion in any battery of fitness to drive tests is the Useful Field of View test (UFOV)[2]. UFOV subtests appear to depend heavily on speed of visual processing, this is particularly so for scores on the recently developed PC version of UFOV used here, and on indexing crowding in peripheral vision. However, UFOV is a proprietary instrument and the literature on UFOV does not directly address the processes involved in UFOV performance. Researchers at the Department of Psychology, University of Adelaide have studied extensively speed of visual processing and crowding in peripheral vision. Custom software is available to measure performance in these domains.

A sample of 60 participants, 33 males (mean age 67.3, *SD* = 6.5 years) and 27 females (mean age 62.4, *SD* = 3.9 years), completed UFOV. They also completed inspection time (IT), a measure of speed of visual processing, and crowding across the visual field (CAVF), a measure indexing effects of strength of crowding in peripheral vision. All of these measures were completed twice, once at each of two sessions held about one week apart. Visual acuity and contrast sensitivity were also measured.

Thus, the current study compared performance on UFOV, inspection time (IT) and crowding across the visual field (CAVF). The expectation was that IT would share substantial variance with all UFOV subtests but particularly with Subtest 1, Processing Speed. It was also expected that CAVF would share variance with Subtest 3, Selective Attention to the extent of the reliability of both measures.

The main outcomes here were that the IT and CAVF measures had high test-retest reliability over a period of about one week and did not exhibit statistically significant practice effects. By way of contrast, although UFOV measures were also highly reliable, two of three UFOV measures, Divided Attention and Selective Attention, showed practice effects; the third measure, Processing Speed, showed severe range restriction in the current sample of healthy older adults. Correlations between CAVF, IT and UFOV Selective Attention were very high, especially when corrected for unreliability of these measures.

These outcomes suggests that IT and CAVF together may well prove appropriate and useful as part of an assessment of fitness to drive. This suggestion needs to be validated by a research program that investigates whether these tests predict crash risk in the same way that UFOV does.

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1 Introduction

The elevated crash risk for older drivers may reflect a small increase in risk for all older drivers, or a large increase in risk for a few (or some combination). It seems likely that there is a large increase in risk for a small subset of older drivers. Assuming that this is so, it would be beneficial to be able to determine which older drivers were at an elevated risk.

Some reviews on the literature on elderly drivers and fitness to drive argue that a test battery to establish fitness to drive should include a test of peripheral vision. No such test is currently included in most jurisdictions.

There are a number of tests that could conceivably be used to determine which older drivers are at the greatest risk. One such test that is currently the focus of much research attention is the commercially available Useful Field of View test (UFOV). It has been claimed that performance on UFOV is the best single predictor of crash risk for elderly drivers.

What follows is a review of research on UFOV. This is then followed by a discussion on two of the subtests from UFOV, Subtest 1 Processing Speed and Subtest 3 Selective Attention, in the context of two well-studied phenomena of visual perception 'inspection time' (IT), a pattern backward masking task which measures speed of visual processing; and 'crowding,' whereby an easily recognised target in peripheral vision is rendered unrecognisable by the presence of flanking stimuli. Next, a study is reported in which performance on UFOV is examined for relationships with IT and a measure of decrement in visual performance due to crowding, strength of crowding. The aim was to explore relationships of UFOV to these well-studied phenomena with a long-term view to developing fitness to drive tests incorporating software packages developed in the Psychology Department, University of Adelaide.

1.1 Older drivers are over-represented in at-fault crashes

It is well documented that older drivers are over-represented in at-fault road crashes (Holland, 2001; Wylie, 1996). When distance travelled is taken into account then older people contribute to a disproportionate number of both pedestrian and driver crashes and to cited traffic violations (Bilban & Zlender, 1998; Evans, 1991; Hakamies-Blomqvist, 1993; Tasca, 1998). This trend needs to be carefully considered in the context of an ageing population, more widespread licensure in older adults, and the increasing probability of older drivers surviving crashes (Payne & Hahn, 1992). Current licensing legislation in Australia already addresses some of these issues. In South Australia, all drivers are required to take a vision test and obtain a medical certificate yearly beyond the age of 70 years (AUSTROADS, 1998). All states but Victoria mandate that by the age of 75 years, a vision test must be taken in order to retain a current drivers licence.

Notwithstanding, it is important to note that the majority of older drivers are crash-free. As the legislation reflects, to restrict an individual's driving rights based only on chronological age is inappropriate and discriminatory (Ball and Owsley, 2003; Goode et al., 1998). Moreover, the ability to drive a motor vehicle is a central aspect of independent living for many seniors. Driving an automobile affords numerous opportunities for enhanced social networking and improved quality of life, particularly in suburban communities (McPherson, Michael, Ostrow, & Shafron, 1988). Without the licence to drive, seniors may no longer be able to hold gainful employment, participate actively in community volunteer activities, manage a household, engage in various recreational pursuits, or establish and maintain social and interpersonal relationships (Klavora & Heslegrave, 2002). Therefore, the only appropriate means of restricting licences is on the basis of deficits in abilities known to increase the risk of crashing, such as poor visual acuity.

To date, research has focused on crash risks associated with older drivers and the analysis of older drivers' crash-involvement patterns (Evans, 1991; Hakamies-Blomqvist, 1993, 1994; Lundberg, Hakamies-Blomqvist, Almkvist, & Johansson, 1998). Evaluation of skills and abilities needed for safe driving is important because older adults often have characteristics that may increase their crash risk. Therefore, a major area of crash research is aimed at characterising sensory, cognitive, and motor capabilities that might be good predictors of driving ability and crash risk.

1.2 Unique crash profile of older drivers

Older drivers have been identified as having a unique profile of road crashes. They are more likely to be involved in crashes and traffic citations involving failure to heed signs, yield right of way, or turn safely (Keskinen, Ota, & Katila, 1998; Morgan & King, 1995; Tasca, 1992). In Australia, as in Europe and America, crash patterns reveal an over-representation of older drivers involved in crashes at intersections (Hakamies-Blomqvist, 2003; Rotter and McKnight, 2002; Insurance Institute for Highway Safety, 2001). Research into the relationship between age and driving has found that older drivers are less able to detect a change in the direction of travel of other vehicles (Sekuler & Ball, 1986), make poorer estimation of the speed of other vehicles (Scialfa, Guzy, Leibowitz, Garvey, & Tyrrell, 1991; Hills and Johnson, cited in Hills, 1980), and are less sensitive to detecting movement in other vehicles (Tran, Silverman, Zimmerman, & Feldon, 1998), particularly when the movement is angular (Henderson and Burg, 1974), or the speed of movement changes.

Older drivers have a higher percentage of crashes attributable to perceptual errors (Storie, 1977). Finnish road-crash data, for example, indicate that attention errors involving perception were the most important causal factor behind fatal crashes involving older drivers. A large percentage of these drivers were not aware of the potential risks before the crash (Hakamies-Blomqvist, 1994). These crash patterns suggest that older drivers have problems with complex perceptual and cognitive functions involved in driving.

1.3 Peripheral vision and the useful field of view

During the process of normal ageing there is substantial neural loss and a gradual decline in dynamic vision, including peripheral vision (Tran et al., 1998; Willis & Anderson, 2000; Wist, Schrauf, & Ehrenstein, 2000). Wojciechowski, Trick, and Steinman (1995) found substantial age-related deterioration in motion sensitivity in the peripheral visual fields and Panek, Barrett, and Sterns (1977) reported a decrease in the extent of the total visual field from 170 deg in young adults to 140 deg by the age of 50 years. This reduction in extent of peripheral vision is important because people with poor peripheral vision are believed to have twice the crash rate of those with normal peripheral vision (Morgan & King, 1995); additionally, poor peripheral vision is associated with problematic driver performance (Wood & Troutbeck, 1995).

Ball, Beard, Roenker and Miller (1988) examined peripheral vision changes as a function of age. They examined peripheral vision in the context of a so-called useful field of view which they defined as the visual area from which information can be acquired within one fixation of the eye. They examined the effects of age on performance on a peripheral localisation task in 24 young (aged 22-23 years), middle-aged (aged 40-49 years), or older (aged 60-75 years) adults. Their findings indicated that regression models which best captured the effects of eccentricity, centre task demand, and practice on peripheral localisation performance were different for the different age groups. For example, age was only a statistically significant predictor of performance in the models for the middle-aged and older groups; similarly, effect of distractors was only statistically significant for the older group. Nonetheless, all three regression models successfully predicted the extent of the useful field of vision when distractors were placed within the visual field.

Ball et al.'s (1988) findings also provided confirmation of research reported only a year earlier. Scialfa, Kline and Lyman (1987) used a visual search task to study target detection in older adults. They presented people with unflanked targets, targets flanked on each side by one noise element (non-target letter), or targets embedded in a horizontal row of 19 noise elements. An Age x Noise Level x Eccentricity interaction showed that differences between young and older participants were largest for peripheral targets presented in noise. In fact, analyses of response latency data showed that the performance of older adults on the low-noise condition was most similar to that of younger adults in the high-noise condition. In both this study and that of Ball et al., the researchers concluded that the differences in peripheral function were due to the fact that older adults take smaller perceptual samples from the visual scene and scan these samples more slowly than do younger adults.

Burton (1997) confirmed that older individuals need more time to scan the visual scene and therefore need longer to perceive targets presented in peripheral vision. Participants searched for a target presented among different numbers of distractor items. When participants were given as much time as they needed to find the target, search times were independent of the number of distractor items and search time increased with distance from the fixation point, for all ages. However, older participants' searches required more time at all target eccentricities. In another experiment, search accuracy was assessed when the targets were only presented at brief exposure durations. Localization errors were greater and increased with target eccentricity to a greater extent for the older adults, suggesting that they did not have enough time to process and encode the location of the target. Results from this study imply that the processes underlying visual search in older adults are functioning at a slower rate; this slowing may affect performance on complex and time-critical tasks. When older adults are forced to search for targets in a time-limited task, they make more errors and these errors tend to increase with eccentricity to a greater extent than for young adults. This outcome is consistent with the notion of a restricted useful field of view in older adults. Thus, the size of an individual's useful field of view can be manipulated by varying stimulus duration and both stimulus duration and stimulus eccentricity interact with age in a predictable way.

Other research suggests that as cognitive load is increased the functional range of peripheral vision (i.e., the extent of peripheral vision from which information is processed) becomes restricted (Ikeda & Takeuchi, 1975). In three separate experiments on a total of 77 participants, Williams (1989) found that the useful field of view is very sensitive to foveal load. As a primary task in foveal vision became more difficult, the extraction of information in peripheral vision worsened. Moreover, performance became increasingly poor as the eccentricity of the peripheral image increased. Critically, the functional extent of peripheral vision under complex, real-world conditions, such as detecting stimuli in cluttered backgrounds, is not equivalent to the maximum extent of peripheral vision that can be measured with clinical peripheral vision tests (Owsley, Ball & Keeton, 1995).

Standard clinical peripheral vision tests measure the useful field of view under the most basic conditions. The observer simply localises a peripheral stimulus presented on a uniform field. Task difficulty is increased by embedding the peripheral target within distractors, or by limiting the observer's exposure to the targets; these manipulations can decrease the useful field of view considerably (Ikeda & Takeuchi, 1975; Sekuler & Ball, 1986; Williams, 1982). However, standard clinical measures are only weakly correlated with vehicle crashes (see Henderson & Burg, 1974; Hills & Burg, 1977; Shinar, 1977) and so a great deal of effort has been directed to developing new techniques for evaluating age-related deterioration of peripheral vision. One of these tests is the focus of this report and is discussed next.

1.4 The Useful Field of View (UFOV) task

Following their initial study in 1988 and in light of other research such as that described above, Karlene Ball and her colleagues developed a new test of peripheral vision that incorporated complex visual task demands: the Useful Field of View task (UFOV). The UFOV measures the extent of the visual field within which targets can capture attention during a brief period (Goode et al., 1998). The three subtests of UFOV measure an individual's speed of processing under increasingly complex visual task demands. To date, the majority of research on UFOV has been conducted using the so-called standard version of the UFOV. However, UFOV has evolved from the standard version to a briefer version which can be administered on a personal desktop computer (PC version, see Edwards, Vance et al., 2005) using either a touch screen or mouse response option. The subtests of the standard version of UFOV are as follows (fuller descriptions of the PC version of UFOV are provided later, see 2.2.2, below):[3]

Processing Speed

In the Processing Speed subtest, threshold exposure duration for central vision is measured by requiring observers to identify stimuli (either a car or a truck) that are briefly presented in the centre of a computer display.

Divided Attention

The Divided Attention subtest requires the observer to identify the stimulus in central vision and the location of a peripheral stimulus which appears randomly at either 10, 20, or 30 degrees eccentricity along one of eight radial spokes, after they are simultaneously presented.

Selective Attention

The Selective Attention subtest is identical with the Divided Attention subtest, except the peripheral stimuli are embedded within distractors (small triangles).

The duration of the displays for all subtests is varied between 17 ms and 250 ms. A 75% correct threshold (in ms) is derived by a double staircase method. These threshold scores are then translated into a scaled score between 1 and 30 (reflecting the percentage reduction in a maximum 35 degree radius field). These subtest scores are added together to create an overall UFOV score. Higher composite UFOV scores indicate greater impairment, with a score of 90 indicating that the individual cannot identify central or peripheral targets regardless of the amount of clutter in the display and even given the longest stimulus duration. Composite scores of 40 or more represent a substantial functional deficit.

1.4.1 The UFOV and risk of crashing

Much of the research on UFOV has been concerned with confirming that decreases in the useful field of view (operationalised as increased UFOV composite score) are especially pronounced in older observers (Sekuler & Ball, 1986) and, unlike standard peripheral vision and visual acuity tests, are predictive of automobile crashes (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Owsley et al., 1998).

Ball et al. (1993) conducted a large study on older drivers. They assessed 294 people aged 60 to 90 years on a set of commonly used neuropsychological and other cognitive tests, including widely used measures of mental status - the Mattis Organic Mental Syndrome Screening Examination (MOMSSE); attention - Trail Making Test (Part A and Part B); and visual memory - Wechsler Memory Scale-Visual Reproduction Subtest (WMS-VR), and the Rey-Osterrieth Complex Figure Test (Rey-O Copy and Rey-O Immediate). Crash data covering the previous three years were obtained from the Alabama Department of Public Safety. They found that only two variables, UFOV and mental status, were associated with a history of crashes (see also Ball & Rebok, 1994). Since then, Ball and her colleagues have examined the predictive validity of the UFOV by examining correlations with a variety of driving ability measures and by comparing UFOV with other variables that may predict high-risk of crashing.

In a follow-up study, Owsley, McGwin and Ball (1998) examined crash data covering the five years after the initial assessment (i.e., 1993-1998). Among the visual processing variables

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[3] UFOV is Copyright© Visual Awareness, Inc. 1991, 1996 and 2002. We are therefore limited to providing descriptions of UFOV subtests to the extent that they have been described in the public domain, that is, in peer-reviewed literature.

identified as potentially important determinants of crash risk, higher UFOV score was the only one associated with crash history. Older drivers with a UFOV score of 40 or higher (i.e., a 40 percent or greater reduction in the useful field of view, as defined above) were 2.1 times more likely to have incurred a crash during the follow-up period compared with those with a UFOV score less than 40. Note that 56.9 percent of the sample had a UFOV score of 40 or higher. A statistically significant linear trend was observed between crash risk and UFOV score when this was entered in the model as a continuous variable. For every 10 points increase in UFOV score, older drivers had a 16 percent increase in crash risk.

A subset of the data collected in 1993 was also used in order to identify the best set of predictor variables for at-fault crashes over the previous five years (Goode et al., 1998). Logistic regression was used to model the data. The first model was designed to evaluate the predictive ability of the traditional neuropsychological and cognitive tests (see above) and was statistically significant, $\chi^2(6, N = 239) = 20.02, p <.01$). The second model included all the variables entered into the first model plus UFOV score and was also statistically significant, $\chi^2(7, N = 239) = 84.24, p <.001$); moreover, the change in chi-square was also statistically significant. The third model evaluated the UFOV score alone and was also statistically significant $\chi^2(1, N = 239) = 76.04, p <.001$). Results showed that although all three models distinguished between those with high and low crash involvement, the model with UFOV alone had the best overall classification rate of 85.4 percent (compared to 77.4% and 58.6% for the first two models, respectively) and the highest levels of sensitivity (86.3%) and specificity (84.3%).

Recently, UFOV was examined for its ability to predict performance in an on-road driving test (Myers, Ball, Kalina, Roth, & Goode, 2000). In this study, 43 drivers aged 61 to 91 years underwent an evaluation consisting of a set of driver screening tests, including vision screening, a reaction time task, a split-attention task, the Hooper Visual Organization Test, verbal and symbolic sign recognition, UFOV, and an on-road driving test. Logistic regression analyses indicated that UFOV was the best single predictor of the on-road driving test outcome (i.e., pass versus fail). Addition of the other screening tests did not increase predictive validity beyond just UFOV alone. Rizzo, Reinach, McGhee and Dawson (1997) also showed that UFOV performance was predictive of crashing in a driving simulator.

1.4.2 UFOV as a fitness to drive test

The literature described above establishes that UFOV score is correlated with risk of crashing. However, evidence on UFOV is not universally favourable to the test. At least one study (Brown, 1993) has failed to support the validity of UFOV which may be important given that a considerable amount of research on UFOV has been conducted by, or in consultation with, the developers of the test. Nonetheless, the vast majority of research shows that UFOV is a useful tool in predicting driving ability and crash risk and UFOV score is also correlated with age (Myers, Ball, Kalina, Roth & Goode, 2000; Fisk, Owsley & Mennemeier 2002; Owsley, McGwin and Ball, 1998; Sekuler, Bennett & Mamelak, 2000). However, when Kane (1996) assessed the utility of UFOV for predicting the safety of drivers based on their driving history, he found that UFOV scores were only minimally related to the driving history categories. That is, UFOV score was not a good predictor of crash involvement. Indeed, in this study, UFOV performance was most closely related to the age of the participants.

In this regard, Sekuler et al. (2000) tested participants ranging from 15 to 84 years to examine whether UFOV scores changed systematically as a function of age. The results showed that deterioration in UFOV score begins early in life (by 20 years, or younger). A high correlation between UFOV score and age undermines the argument for UFOV as a fitness to drive test, given the emphasis by the developers of UFOV on measuring individual differences among older adults. Unsurprisingly, therefore, Ball and Owsley (2005) argued against this possibility claiming that UFOV assesses cognitive impairments that affect driving ability for individuals of all age groups, not just the older driver. Barr and Eberhard's (1994) research appears to support their claim. They reported that UFOV relates driving crashes to visual, perceptual and cognitive abilities, not to age. They claimed that once performance on UFOV was statistically controlled, there were no residual effects of age on the probability of a crash over five years among a sample of drivers aged 55 years or over (Barr & Eberhard, 1994).

1.4.3 The UFOV as a measure of cognitive decline

Research has established that increase in UFOV score is correlated with cognitive decline in patients with human immunodeficiency virus (HIV), multiple sclerosis (MS), or traumatic brain injury (TBI). Marcotte et al. (2004) found that HIV patients who were identified as neuropsychologically impaired (NP-) had poorer performance on UFOV Processing Speed and Divided Attention subtests than did neuropsychologically normal controls, although their overall UFOV risk classification was similar. In this study, the cognitively impaired groups (HIV+NP-, MS+ and TBI) also had higher rates of crashing. For example, the HIV+NP- patients had a higher number of simulator crashes, were less efficient at completing a navigation task, and were more likely to fail an on-road evaluation. As the mean age for the HIV+NP- group was not statistically different from the cognitively normal groups, these findings support the claim by Ball and her colleagues that UFOV is predicting crash risk based on relevant cognitive abilities, not on chronological age.

Schultheis, Garay and DeLuca (2001) reported that UFOV performance was poorer for multiple sclerosis patients with cognitive impairment (MS+) than for patients with MS but without cognitive impairment (MS-), and for healthy controls. Again, the MS+ group demonstrated poorer performance on two of the three UFOV subtests. Additionally, a higher percentage of MS+ individuals were rated within the UFOV high risk (i.e., probability of crash involvement) category, relative to the MS- and healthy controls

The objective of a study by Fisk, Novack, Mennemeier and Roenker (2002) was to explore the possibility that UFOV performance is compromised after TBI. They compared UFOV performance of 23 male and female TBI patients and 18 young adults without neurological impairment. They found that TBI patients had higher UFOV scores than the young adult controls which, they argued, indicated a functional loss of peripheral vision in the TBI group. When UFOV subtests were considered, the TBI group had significantly higher scores on Divided Attention and Selective Attention than did the control group. A possible limitation of this study was that the TBI group was substantially older than the control group (mean age 38 versus 25 years), although previous studies of UFOV have not found such differences between people of these ages.

1.4.4 The UFOV and cognitive abilities tests

Ball and her colleagues have not published convincing evidence on what underlying cognitive processes they believe that UFOV actually measures nor have they reported any consistent pattern of correlations between UFOV and other cognitive abilities tests. Fisk et al. (2002) reported one of the highest correlations published between the UFOV task and a test of cognitive abilities. They found that UFOV was correlated with the Trail Making Test-B (r = -.603, p =.003, N=22). The Trail Making Test is a neuropsychological instrument widely thought to assess speed of visual search, attention, mental flexibility, and motor functioning. The task provides an opportunity to observe an individual's ability to deal with multiple stimuli, something that is important to driving. The relationship between these measures is intriguing considering that both UFOV and Trail Making Test-B results are correlated with driving evaluation outcomes (Goode et al. 1998).

Goode et al. (1998) also conducted correlational analyses to compare UFOV to other cognitive tests identified as measures of mental status, attention, and visual memory. Results indicated that UFOV score was correlated with all measures, ranging from r = -.35 (Rey-O Copy) to r = -.46 (WMS-VR) for visual memory tasks; r = .45 (MOMSSE) for mental status; and r = .51 (Trail Making A) and r = .52 (Trail Making B). However, these correlations are not particularly useful in understanding what UFOV actually measures because most cognitive abilities tasks will be correlated with each other (Carroll, 1993).

By contrast, Fisk et al. (2002) reported correlations between UFOV and other measures such as IQ (*r* = -.310, *p* = .172, *N*=21), Digit Span (*r* = -.242, *p* = .319, N=19), the California Verbal Learning Test (*r* = .028, *p* = .904, *N*=21) Trail Making Test-A (*r* = -.080, *p* = .722, *N*=22) and the Grooved Pegboard Test (right, *r* = .186, *p* = .408, *N*=22; left, *r* =.073, *p* = .747, *N*=22) that were uniformly low but their sample size was small.

The lack of robust correlations between UFOV and neuropsychological measures assessing intelligence, auditory attention, verbal memory and motor ability suggests that UFOV is not a global measure of cognitive abilities but rather a specific measure of visual processing, attentional processing, or both of them, as reflected, perhaps, by the correlation with the Trail Making Test-B.

1.4.5 Decrements in performance on UFOV – what does UFOV measure?

Previous studies of poorer UFOV performance in older adults give rise to conflicting interpretations about the nature of UFOV deficits. One set of studies suggests that UFOV deficits in older adults result from a restricted useful field of view in which stimuli at greater eccentricities are more difficult to detect (Ball et al., 1988; Sekuler & Ball, 1986). Fisk et al. (2002) used the following analogy to describe this: if one thinks of visual attention as being like a spotlight used to see in a dark area, the restricted useful field of view hypothesis would be like the beam of a spotlight becoming narrower without losing any of its intensity. By contrast, other investigators report that poorer UFOV performance in older adults is not eccentricity dependent because people in all age groups make errors at greater eccentricities (Ball et al., 1993; Rizzo et al., 1997; Sekuler, Bennet & Mamelak, 2000). Older adults tend to make more errors at all eccentricities, suggesting that the useful field of view *per se* is not really restricted. The deficit seems to be an inefficiency at detecting stimuli throughout peripheral vision (Seiple, Szlyk, Yang & Holopigian, 1996). To use Fisk et al.'s spotlight analogy again, this would be like a spotlight with a constant diameter beam that has become dimmer, meaning one is less able to detect stimuli throughout the range of the beam.

The results of the Fisk et al. (2002) study of TBI patients seem more consistent with the latter interpretation. On UFOV Divided Attention, TBI patients make more overall errors, but both TBI and control groups made a relatively consistent number of errors at all eccentricities. By contrast, both groups made more errors at greater eccentricities on the Selective Attention subtest. The TBI patients did not have proportionally greater impairment at higher eccentricities, which argues against the restriction of the useful field of view hypothesis. Sekuler et al., (2000) seem to agree with this interpretation. This deterioration in UFOV performance is best conceptualised, then, as a decrease in the efficiency with which observers can extract information from a cluttered scene, rather than by a shrinking of the field of view. The diminished efficiency among elderly observers is exacerbated when conditions require the dividing of attention between central and peripheral tasks.

1.5 UFOV, inspection time and crowding across the visual field

The remainder of this review considers aspects of UFOV performance in terms of two well-studied phenomena: speed of visual processing and crowding across the visual field. Speed of visual processing is assessed by all three subtests of UFOV but is the only aspect of performance tapped by Subtest 1, Processing Speed. Subtest 3, Selective Attention builds on Subtest 2, Divided Attention, by introducing distractors across the display and *prima facie* involves crowding across the visual field.

1.5.1 Speed of visual processing

UFOV subtests are structured progressively and build on performances evaluated in the prior subtest(s). Thus, for example, Processing Speed, measured in Subtest 1 of UFOV is also a factor in performance on Subtest 2, the Divided Attention measure. Researchers from diverse disciplines seem to agree that speed of information processing slows with age (Salthouse, 1985; Schaie, 1996). Individuals with slower processing speed rely on longer visual persistence to identify and recognise targets, which is not always possible in situations where targets only appear briefly in the visual field. Multiple perceptual demands, or the presence of distracting stimuli, can further affect processing speed. Speed of processing is slower when there is competition for attention, or added distraction.

Subtest 1 of UFOV, Processing Speed, is a type of visual backward masking task; such tasks are often used to estimate the speed of the visual system (see e.g., Burns, Nettelbeck, White & Willson, 1999). In a pattern backward masking task, a target is presented for a brief period followed by a patterned mask. In UFOV, the target is the silhouette of either a car or a truck, displayed in a box in the centre of the screen, and presentation of the target is followed by a mask that covers the whole screen. The observer will only be able accurately to decide which image was displayed if there is sufficient time between the onset of the target and the mask. This minimum period is called a ‘critical stimulus onset asynchrony’ (CSOA) and it is the measurement of the CSOA that provides an index of the speed of the visual system. One pattern backward masking task that has been studied extensively in a number of applied settings is inspection time (IT).

1.5.2 Inspection time

IT is a task that indexes the speed of early stages of visual information processing (Nettelbeck, 1987). The most frequently used IT task involves visual backward pattern masking. Two high-contrast lines are presented side-by-side (one line is markedly shorter than the other) and joined at the top by a horizontal line. There are two alternate targets, one with the shorter line on the left and the other with the shorter line on the right (see Figure 1.1). Observers are simply asked to nominate on which side of the figure the shorter line appeared. Importantly, there is no time pressure imposed on observers when making this judgement. Presentation of the target figure is followed after a variable duration by a pattern mask that overlies the target stimulus (see Figure 1.1). Thus, the difficulty of the task is manipulated by varying the duration between the onset of the target figure and the onset of the masking figure. IT is therefore an estimate of threshold accuracy and is defined as the stimulus onset asynchrony (SOA; i.e., duration between target onset and mask onset) at which the task is solved at some arbitrarily high level of accuracy (e.g., 80%).

According to contemporary integration theory of pattern backward masking, the masking effect results from poor fine temporal resolution within the visual system (Coltheart & Arthur, 1972; Di Lollo, 1980; Eriksen, 1980; Eriksen & Schultz, 1978; Felsten & Wasserman, 1980; Sheerer, 1973). That is, at short SOAs the target and mask are temporally integrated and are therefore indistinguishable. At longer SOAs the features of the target and mask become distinguishable (Burns, Nettelbeck & White, 1998; White, 1996). This analysis of the task contrasts with the original rationale (Vickers, Nettelbeck & Willson, 1972; Vickers & Smith, 1986) wherein the lengths of the two lines were compared and evidence accumulated in quanta until a decision was reached. According to this perspective, the backward mask was employed to prevent sampling from the ‘iconic store’.

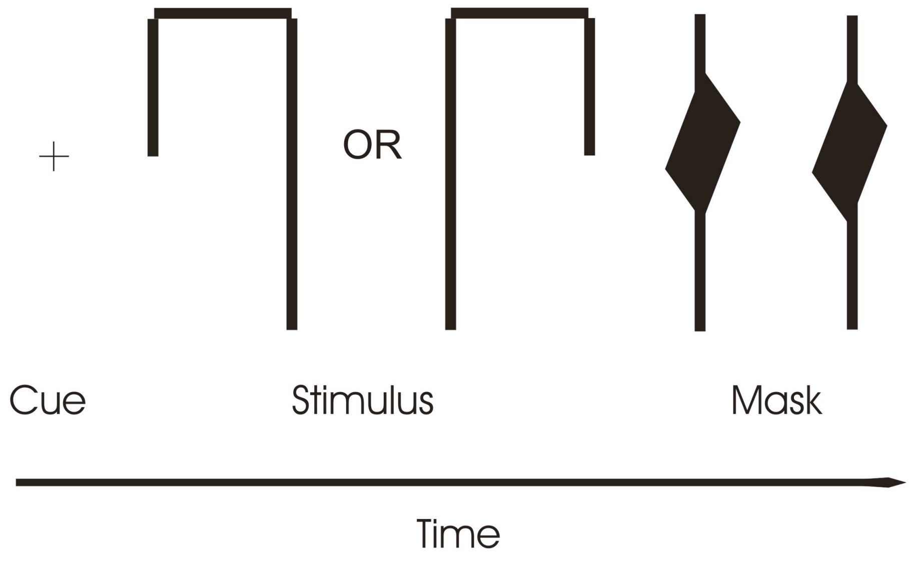

Figure 1.1.

Warning cue (left), two alternative IT target figures (centre), and lightning mask (right) for the inspection time (IT) task

There have been three substantial reviews that have established that there is a moderately strong relationship between inspection time (IT) and IQ (Grudnik & Kranzler, 2001; Kranzler & Jensen, 1989; Nettelbeck, 1987), a conclusion confirmed by two overviews of the measure (Deary, 1996; Deary & Stough, 1996). The reviews focussed in turn on the relationships of IT with verbal, performance, and general IQ. The reviews reached similar conclusions about the correlation between IT and IQ. Briefly, the pattern has been that IT correlates most strongly with performance IQ, rather than with verbal IQ from the Wechsler scales, and with putative tests of general intelligence (i.e., *g*) such as Raven's matrices. A common interpretation of this pattern of relationships has been that performance IQ and matrices tests are measures of fluid ability and therefore IT provides an index of a biological substrate that underpins what is commonly understood by the term 'intelligence.'

In more applied settings, it has been found, for example, that IT is substantially longer for intellectually disabled individuals (Nettelbeck, 1985) and is lengthened by small quantities of alcohol (reviewed by Moskowitz & Robinson, 1988). Of more relevance to the driving task are the findings that IT is longer for older adults (summarised by White 1996). This increase in IT for older adults reflects the more general decline in speed of processing found in the elderly and is thought to be causally prior to the decline found in performance by the elderly on measures of higher-order cognition (Kail & Salthouse, 1994; Nettelbeck & Rabbitt, 1992). Burns et al. (1999) measured IT under optimal versus marginal conditions (as determined by the visible light transmittance of tinted car windows), reporting that IT estimates were longer as viewing conditions worsened and that the IT estimate increases were greater for the older participants. Finally, in the current context, it is worth noting that sex differences are not important for IT (Burns & Nettelbeck, 2005).

1.5.3 Crowding across the visual field[4]

What is visual crowding

Vision researchers have applied the term ‘crowding’ to different phenomena – not all of which are necessarily related. The phenomenon investigated by Bouma (1970) will be taken as paradigmatic. Bouma explored the effect of flanking letters on the recognition of single target letters, in normal peripheral vision. The target letters were large enough to be recognisable in the near periphery when presented in isolation. They were briefly presented on the horizontal meridian at different eccentricities (where ‘eccentricity’ is the distance from fixation in degrees of visual angle). They could be presented alone, or flanked by a letter to the left and/or right. The separation distance (in degrees of visual angle) between the flank(s) and target was varied. Bouma (1970) discovered that the flanking letters interfered with the recognition of the target letter over very wide separation distances – of up to 0.5 times the eccentricity. For example, a recognisable target letter presented at 10 degrees eccentricity could be rendered unrecognisable by the presence of flanking letters up to 5 degrees to its left and right. The widest separation distance where recognition first becomes difficult, 5 degrees in the example given, is known as the ‘critical separation’. Bouma also discovered that the outer flanking letter (further from fixation) provided stronger interference (i.e., had a wider critical separation). He noted that the strength of interference was roughly the same in the left and right visual fields. He did not find any evidence of contour interaction in central vision.

Bouma (1970) used the vague term ‘interaction effect’ to describe this phenomenon. In later work (Bouma, 1973, Bouma & Legein, 1977) he used the term ‘visual interference’. He never used the term ‘crowding’, although Stuart and Burian (1962) had introduced it a decade earlier to describe a possibly related phenomenon. Bouma’s phenomenon will be referred to as ‘crowding’ in this paper.

Bouma (1970) was interested in reading. He considered that crowding limited the size of the ‘functional visual field’ to about four letters, which, in turn, provided a major constraint on the reading of normal text. The idea that crowding limits the ‘visual span’ is still important in the literature on reading (Legge, Klitz & Tjan, 1997; O’Regan, 1990). Bouma and Legein (1977) also raised the possibility that excessive crowding in near-central vision could be responsible for some cases of visual dyslexia. Bouma’s interest in crowding was limited to empirical research on factors affecting the strength of crowding, and to the possibilities of relating that research to normal reading and dyslexia. He never developed a theory of crowding.

Crowding theories

Visual perception is generally considered to involve two main stages of processing: detection/analysis followed by integration/synthesis. According to Graham (1989, p. vii) “The visual system first breaks the information in the visual stimulus into parts, and then puts the information back together again”. Vision scientists have a much fuller understanding of the processes involved in the first stage than in the second. In the words of Graham (1989, p. vii) “Just as with all the King’s men and Humpty Dumpty, current vision science knows much more about the parts than about the subsequent computations that put them back together again”.

There are two main theories of crowding. The ‘pattern masking’ theory involves processes at the level of feature detection/analysis, while the ‘feature pooling’ theory involves processes at the level of feature integration/synthesis. The pattern masking theory was independently proposed in two papers that were published in the early 1960s. The feature pooling theory was independently proposed by two research groups about forty years later.

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[4] This section was contributed by Dr Michael White, South Australian Department of Transport, Energy and Infrastructure.

The two theories of crowding are now discussed in some detail.

The pattern masking theory of crowding

The ‘Landolt C’ is a black annulus with a small gap. When the gap is to the right of the annulus, the shape resembles a normal ‘C’. However, the Landolt C has a thicker stroke-width and a smaller gap than a normal C, with the width of the gap usually being equal to the stroke-width. One test of visual acuity involves presenting the Landolt C in different orientations, with the subject being required to determine whether the gap is at the top, bottom, left or right. The size of the Landolt C is reduced until the position of the gap can no longer be visually resolved. The threshold size of the Landolt C provides a measure of visual acuity (see 2.2.1.1, below). Flom, Weymouth and Kahneman (1963) found that detecting the position of the gap in normal central vision was adversely affected by placing four small black bars, of the same height and stroke-width as the Landolt C, tangentially at the top, bottom, left and right of the Landolt C. They discovered that the bars were only effective at reducing acuity when they were very close to the Landolt C: the effect was strongest when the bars were almost touching the Landolt C, and was reduced to zero when the bars were separated from it by a distance of greater than about five gap widths (which is approximately equal to the width of the Landolt C). They referred to this effect as ‘contour interaction’. In current terminology, the effect is known as ‘pattern masking’. In a further experiment, Flom, Heath and Takahashi (1963) discovered that contour interaction could also be obtained when the Landolt C was presented to one eye, and the surrounding bars were presented to the other. From this, they concluded that the effect is not retinal, but occurs in the brain, after the confluence of information from both eyes.

In 1991 (twenty-eight years after his original research), Flom reviewed his own research on contour interaction using the Landolt C with bars in normal central vision, as well as the extension of that research into normal peripheral vision by Jacobs (1979). He maintained that, for all of the subjects investigated, the extent of contour interaction was proportional to the level of simple visual acuity found in the same region of the retina. His theory of contour interaction was largely based on that fact. Flom (1991) concluded that contour interaction was “a type of spatial lateral masking” (p. 237) that involved “properties of the receptive field” (p. 243). In other words, he believed that contour interaction involved interference between the representations of adjacent stimuli at the level of feature detection/analysis. Where there were small receptive fields, for example in cental vision, there would be good acuity and a small zone of contour interaction; and where there were large receptive fields, for example in peripheral vision, there would be poor acuity and a large zone of contour interaction. He assumed that this process occurred at an early sensory level of neural processing (in the lateral geniculate nucleus or the occipital cortex).

Although it is conceivable that ‘real’ crowding, as investigated by Bouma (1970), is nothing more than contour interaction, Flom (1991) made a clear distinction between the two. He concluded that contour interaction was different from crowding in the following respects. While contour interaction can be found in simple stimuli (such as a Landolt C with bars), crowding requires multi-element displays (such as Bouma’s three-letter display). While contour interaction occurs in normal central vision, crowding does not. While contour interaction is limited to distances less than the width of the target, crowding can operate over distances of many target-widths. While contour interaction only occurs at near-threshold target sizes, crowding is normally demonstrated using targets that are well above threshold size.

Stuart and Burian (1962) proposed their version of the pattern masking theory at much the same time as Flom et al. (1963a, 1963b). However, their work is not discussed here in any detail, as their experimental displays were complex, and their results correspondingly ambiguous. Nevertheless, their theory deserves to be mentioned. Like Flom et al. they concluded that ‘separation difficulty’ (similar to ‘contour interaction’) in central vision was “quantitatively related to the level of visual acuity” (p. 477). They theorized that separation difficulty was “related to the behaviour of contrast on the retina”, and that the “irradiation of excitation” from the flanks would reduce the visibility of the targets (p. 476). In those respects, the two set of findings, and the two theories, are identical. However, Stuart and Burian (1962) made much stronger claims for their theory than did Flom (1991). Whereas Flom claimed that contour interaction was not relevant to real crowding, Stuart and Burian promoted their theory as a general theory of ‘crowding’ (the term they introduced).

Acuity scaling vs size scaling

Flom (1991) had maintained that extent of pattern masking was proportional to the level of simple visual acuity found in the same region of the retina. That finding is known as ‘acuity scaling’, and is taken as evidence that both simple acuity and pattern masking are mediated by simple receptive fields, the size of which increases with eccentricity. However, the acuity scaling aspect of the pattern masking theory fails to incorporate current understanding of feature detection/analysis. Various researchers, including Pelli, Palomares and Majaj (2004), realised that acuity scaling referred only to the smallest discernable shapes, and that the concept had to be extended to account for the fact that there is a range of receptive field sizes at every eccentricity. The extended concept of ‘size scaling’ refers to the fact that the most effective pattern mask is the same size as the target, irrespective of eccentricity.

Distinguishing between pattern masking and crowding

The relationship between pattern masking and crowding has been the focus of recent interest by two research groups: one headed by Dennis Levi of the University of Berkley, and the other by Denis Pelli of New York University. One aim of both research programs was to clarify the relationship between pattern masking and crowding. A second aim was to develop the ‘feature pooling’ theory of crowding. Although using very different stimulus displays, the two research groups reached the same conclusions with respect to both aims.

In 2001 and 2002, Levi and his colleagues published three papers on the relationship between pattern masking and crowding in normal vision (Chung, Levi & Legge, 2001; Levi, Klein & Hariharan, 2002; Levi, Hariharan & Klein, 2002). In 2005, they replicated and summarised their earlier research (Hariharan, Levi & Klein, 2005). However, they used very complex stimulus displays, and in the interests of simplicity and brevity their work is not discussed here any further.

Pelli et al. (2004) used a variant of the stimulus display first used by Bouma (1970). Both types of display involved the presentation of a target letter on the horizontal meridian. In both displays, the target letter was flanked by one or more other letters. In both displays, the eccentricity of the target could be varied, as could the separation distance between the target and the flanks. The difference between the two approaches involved the method used to determine the ‘critical separation’. For Bouma, the critical separation was the widest separation distance where recognition of the target first became difficult. As mentioned previously, Bouma discovered that the critical separation was approximately equal to half the eccentricity. Pelli et al. (2004) realised that the target could always be recognised, even at separation distances that were much shorter than the critical separation, if it were made much brighter than the flanks. They used a mid-grey background, and medium-contrast flanks that were brighter than the background. They used a target that was also brighter than the background, but of variable contrast. At wide separation distances, the target could be recognised even when its contrast was quite low. As the separation distance was reduced, a point was reached where the contrast of the target had to be greatly increased for it to be recognised. That distance defined the critical separation.

In their empirical research, Pelli et al. (2004) conducted a number of experiments in which they replicated many of the main published findings on crowding, as well as making some discoveries of their own. They replicated Bouma’s (1970) finding that the critical spacing is proportional to eccentricity, as well as his finding that the outer flank provides stronger crowding than the inner flank. If crowding were the result of simple pattern masking the opposite result would have been predicted, because the stronger mask would be the one closer to the focal point.

Flanks could be presented above and below the target as well as to the left and right (the normal procedure). For a target 6 degrees to the right of fixation, Pelli et al. (2004) found stronger crowding for flanks to the left and right of the target, than for flanks above and below it. In doing so, they replicated the interesting discovery by Toet and Levi (1992) that crowding along a radius centred at the fovea is stronger than crowding along the circumference.

In one of their experiments, Pelli et al. (2004) increased the width of the stimuli (both the target and the two flanks) from 0.32 degrees to 2 degrees, while keeping the target at a fixed eccentricity of 4 degrees. They found that the critical separation remained constant at about 1.2 degrees, irrespective of stimulus size. That result contrasts with the findings of other researchers for pattern masking, where the critical separation is proportional to target size (i.e., where there is size scaling).

Pelli et al. (2004) found that the strength of crowding was relatively unaffected by the number of flanks. Two flanks (e.g., to the left and right of the target) provided only slightly stronger crowding than one (e.g., to the right of the target), and the addition of two further flanks (e.g., above and below the target) had little extra effect. Pelli et al. also discovered that the size and shape of the flanks were relatively unimportant. Furthermore, the contrast of the flanks was unimportant provided that they were bright enough to be seen. In other words, there is little ‘stimulus specificity’ for crowding. This is another respect in which crowding differs from pattern masking – which is only found where the target and mask are very similar in most respects.

Pelli et al. (2004, p. 1143) summarised the main differences between pattern masking and crowding in their Table 2, which is partly reproduced here (Table 1.1).

Table 1.1
Comparison of crowding and pattern masking
(source: Pelli et al., 2004)

Crowding	Pattern Masking
Does not occur in central vision. Only found in peripheral vision.	Occurs in both central and peripheral vision.
When crowded, the target remains visible, although it is not recognisable.	The target disappears when suppressed by the flank (mask).
The flanks can produce strong crowding at wide separation distances.	The flank (mask) must be very close to overlap the target.
The critical spacing depends on eccentricity (Bouma, 1970), and not on target size.	The critical spacing depends on target size and not on eccentricity.
The mask can be quite different from the target with respect to shape, size, colour and contrast. In other words, there is very little stimulus specificity.	The mask must be very similar to the target in shape, size and colour. In other words, there is strong stimulus specificity.

Pelli’s ‘morphing’ demonstration

This section on the ‘morphing’ demonstration, and the next section on the feature pooling theory of crowding, are taken fairly directly from Pelli et al. (2004, pp. 1137, 1139-1140, 1155, 1161).

The subjective experience of crowding is very instructive. Examine the two blocks of letters in this demonstration while fixating the central dot:

A A _ B A
A A A B

What you see on the left is a block of four A's. What you see on the right is much harder to describe. It's a block of four letter-like objects. But they are not clearly A's or B's; they are in-between and unstable. Each letter may seem at times to be an A and at times a B, but most of the time it has a confusing hybrid A-B appearance that would be impossible to draw.

It is usually assumed that letter recognition involves dividing the visual scene into small regions, and that all of the letter's properties are 'estimated' from within the same region. Surprisingly, this demonstration shows that a single letter's presence/location and shape are estimated from regions of different sizes. The perceived presence/location of each object distinguishes four objects, arranged in a square. So, the visual system can satisfactorily 'count' and locate the four objects. However, the next step of identifying the shape of each of these objects is apparently much more problematic. To correctly identify each object as a particular letter, its features would have to be assembled over a more-or-less one-letter-wide region. Yet each letter's shape has a hybrid A-B appearance, because information has been integrated from a broader region that includes several letters. This demonstration seriously undermines the notion of object recognition as a unitary process that 'inspects' a region of the image and creates an 'object' with properties. Instead, the demonstration shows that, in peripheral vision, the distinct properties of location (where) and shape (what) are estimated from very differently sized regions.

The 'feature pooling' theory of crowding

Elementary feature-detection theory (Graham, 1989) provides a good account of detecting and identifying a very simple target such as a short line segment (for which the detection of a single feature is sufficient for a correct response). However, identifying a complex pattern such as a letter requires the combination of information from several feature detections to respond correctly. This assembly process is called 'feature integration' (or 'binding').

The feature pooling theory of crowding involves two stages: independent feature detection followed by feature integration. It is assumed that ordinary pattern masking impairs feature detection and that crowding impairs feature integration. In pattern masking, the mask interferes with the target by stimulating the target's feature detector. In crowding, the features of the flanks and the target are detected separately and subsequently amalgamated within the integration field. Crowding exposes the inner workings of the 'feature integrator'. A single object's various perceived properties must therefore be estimated based on regions of very different sizes: a small region for one-feature properties (such as presence or coarse location) that do not require integration, and a large region for multiple-feature properties (such as the shape of a letter) that do require integration.

In summary, the feature pooling theory considers that crowding is excessive feature integration, with integration occurring over an inappropriately large area that includes the flanks as well as the target.

Why does the visual system do something as silly as to integrate the features of a remote flank into the target letter? People do not experience crowding in the fovea, so integration must normally have the right range for an object in the fovea, integrating over the entire region of the object, and not beyond. So why extend it perniciously for signals in the periphery? It seems likely that the visual system has many integration fields of various sizes, overlapping one another, and distributed across the visual field. When possible, the visual system uses an integration field of the same size and location as the object to be identified, and this is what normally happens in the fovea. But in the periphery we lack small integration fields, so we use what we have, which may be inappropriately large. The large ones are 'cheap', because it takes only a few to tile the visual field. Smaller ones are progressively more 'expensive', because tiling requires more of them; so they exist only in the central visual field. (Allowing for overlap in the tiling will increase the number of fields by the overlap factor, without changing the argument.)

The previously mentioned difference of opinion between Stuart and Burian (1962) and Flom (1991) has been resolved in favour of Flom: pattern masking and crowding are two distinct phenomena, and crowding can not be explained in terms of pattern masking.

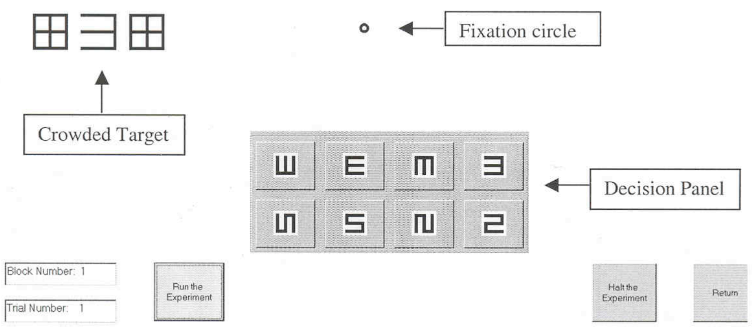
1.5.4 The crowding across the visual field task

This section describes briefly software developed in the Department of Psychology, University of Adelaide, by Michael White to assess, among other aspects of visual performance, strength of crowding across the visual field.

Spatial and temporal masking across the visual field software

The software uses eight alternative targets (see Figure 1.2) that can be presented in any of 187 locations (constituted as a 17 x 11 grid) across the display area. Targets can be flanked horizontally or vertically. As can be seen in Figure 1.2, the flanking stimulus consists of six line elements arranged as a cross within a square; importantly, all eight target figures consist of a subset of the line elements constituting the flanking stimulus. For the purposes of this paper, the task instantiated with this software to assess strength of crowding will be referred to as Crowding Across the Visual Field (CAVF).

The CAVF was designed to use the most appropriate distractor stimuli to maximise crowding: flankers of the same size as the target, and containing all the line segments (features) contained in the target. The display time of the target is set short enough to ensure that participants do not have time to move their eyes from the central fixation point to look directly at the target. This is important to ensure that the participant's scores actually reflect their ability to discriminate patterns in their peripheral vision.



Block Number: 1

Trial Number: 1

Figure 1.2.

Labelled screen shot of the interface used for crowding across the visual field (CAVF) showing target and flanking stimuli and the eight possible targets.

Crowding Across the Visual Field (CAVF)

Corlett and White (2002), in a study on 60 people (30 young adults and 30 older adults), reported two main findings: First, they established that for all participants, CAVF scores (see 2.2.4, below) were affected by the degree of eccentricity at which a target was displayed; second, they reported an age-related decrement in the identification of targets that appeared in peripheral vision. These results are now discussed in more detail.

The main effect found for eccentricity was a linear trend that reflected lower target recognition further from the central fixation point. That is, the crowding effect was stronger at greater eccentricities. While the eccentricity affected all participants' scores, it did have a different effect on the crowded condition for the two age groups. The older group's correct responses fell more sharply with increased distance from the centre, with the young group showing a substantial crowding effect at 2.2 deg visual angle from the central fixation point and the older group showing a substantial crowding effect at only 1.1 deg from the central fixation point. Corlett and White (2002) therefore concluded that the further a crowded target is from central vision, then the more difficult it is to discriminate, and that this effect is stronger for older adults.

The most substantial differences between the two age groups' identification of targets in their peripheral vision appeared in the parafoveal region (i.e., approximately 2-to-4 deg from central fixation). Older participants correctly identified 54% of the crowded targets in the parafoveal region, while the younger group correctly identified 86%. This outcome is consistent with that of Ball et al. (1990) who reported an age related reduction in the diameter of the functional visual field. Although Corlett and White's finding may indicate that the parafovea is the region most sensitive to the effects of ageing, a more likely explanation may be that this finding simply reflects the fact that individual differences are swamped by ceiling effects in central vision and by floor effects at greater eccentricities.

1.6 A study on UFOV, IT and CAVF

The rationale for the current study has the following elements. Older drivers are over-represented in at-fault crashes. These crashes display a unique profile that is consistent with the involvement of deficits in performance at perceptual, motor, and higher cognitive levels, with particular emphasis on speed of information processing deficits. Therefore, in the interests of identifying older drivers at higher risk of crashing, with a view to restricting their driving, fitness to drive tests require development and validation. One particular test that makes claim for inclusion in any battery of fitness to drive tests is UFOV. UFOV subtests appear to depend heavily on speed of visual processing and on indexing crowding in peripheral vision. However, UFOV is a proprietary instrument and the literature on UFOV does not directly address the processes involved in UFOV performance. Researchers at the Department of Psychology, University of Adelaide have studied speed of visual processing and crowding in peripheral vision extensively. Custom software is available to measure performance in these domains.

The current study compares performance in older drivers on UFOV, inspection time (IT) and crowding across the visual field (CAVF). The expectation is that IT will share substantial variance with all UFOV subtests but particularly with Subtest 1, Processing Speed. It is also expected that CAVF will share variance with Subtest 3, Selective Attention, to the extent of the reliability of both measures.

Should these substantive expectations be realised, we would be encouraged to pursue validation of IT and CAVF as potential fitness to drive measures.

2 Method

2.1 Participants

Sixty participants were recruited from the participant panel maintained by the Cognitive Abilities Laboratory, Department of Psychology, University of Adelaide. These people have participated in other studies and were first recruited via advertisements in newspapers or via information on previous studies being featured on television and radio. There were 33 males (mean age 67.3, *SD* = 6.5 years) and 27 females (mean age 62.4, *SD* = 3.9 years). All held current driver's licences. All participants were paid A$20 at the completion of their participation in the study.

2.2 Apparatus and material

Computerised tests were presented on a high performance, 17 inch computer monitor. Screen resolution and vertical refresh rate depended on the particular test (see below).

2.2.1 Vision testing

All participants were tested for visual acuity and contrast sensitivity.

The Freiburg Visual Acuity test

The Freiburg Visual Acuity test (Bach, 1996) is a computerised test that measures visual acuity. Landolt-Cs are presented on a computer monitor in one of four orientations (i.e., the gap in the 'C' is at the top, bottom, left, or right of the figure). The participant presses the corresponding arrow key on a standard computer keyboard to indicate the observed position of the Landolt-Cs' gap. To estimate the acuity threshold, a best PEST (best Parameter Estimation by Sequential Testing) procedure is used in which a psychometric function having a constant slope on a logarithmic acuity scale is assumed. Measurement terminated after 36 trials; every 6th trial was an easy one to encourage optimum performance in this forced-choice task. The estimation algorithm returned decimal acuity for the viewing distance of 60 cm. Screen resolution was 1280 x 1024 pixels and vertical refresh rate was 75 Hz.

Contrast Sensitivity test

The Pelli-Robson Contrast Sensitivity Chart (Pelli, Robson & Wilkins, 1988) has letters grouped on the chart in triplets, with two groups per line on the chart. Within each triplet, all letters have the same contrast; contrast decreases from one triplet to the next. Participants make a single attempt to name each letter on the chart starting at the upper left-hand corner and reading horizontally across each line. Participants are asked to guess even when they believe they cannot see the letters. Testing continues until they guess three letters incorrectly in a row. Contrast sensitivity is defined as the log contrast for the faintest triplet for which two out of the three letters are named correctly.

2.2.2 Useful Field of View (UFOV)

It is important to note that we used the PC version of UFOV (UFOV v6.07 for Windows) which differs from the standard version of UFOV (see 1.4, above). Again, and as noted above, we are constrained from describing the UFOV beyond what currently appears in the public domain. Therefore, our description closely follows that for the PC version of UFOV in Edwards, Vance et al. (2005, pp. 531-533).

Stimuli were presented at a viewing distance of 60 cm with screen resolution 1024 x 768 pixels and a vertical refresh rate of 60 Hz (note, these settings are under the control of UFOV software). Subtest 1, Processing Speed, required identification of a target presented at a central fixation point. The target was either the silhouette of a car or a truck (1.9 deg x 1.4 deg) presented on a black background in a 2.9 deg x 2.9 deg fixation box. Subtest 2, Divided Attention, required identification of this central target along with the localisation (but not identification) of a simultaneously presented peripheral target (1.9 deg x 1.4 deg silhouette of a car). The peripheral target appeared randomly in one of eight directions from the central fixation box (four cardinal and four oblique) at approximately 10.5 deg from the centre of the fixation box. Subtest 3, Selective Attention, is identical with Subtest 2 except that the peripheral target was embedded in distractors (triangles of the same size and luminance as the targets) arranged in concentric circles around the peripheral target. Each trial for each subtest consists of four display screens: 1) a fixation box, 2) a test stimulus, 3) a full-field, white noise visual mask, and 4) a response screen. For all subtests, stimulus durations vary from 17 ms up to a maximum of 500 ms.

Scoring on the PC version of the UFOV differs from that on the standard version (see above). Instead of a percentage reduction in useful field of view, expressed as a score out of 30 for each subtest, scores for the PC version are expressed as 75% threshold scores, in ms, for each subtest. These thresholds are determined by a double staircase method. A score of 500 ms indicates that the participant could not perform the task even at the longest display duration Thus, low scores represent better performance and the lowest possible score is 16.7 ms. Additionally, an overall Risk Category that ranges from 1, ‘Very Low’ to 5, ‘Very High’ is provided by the software and which depends on the threshold outcomes across the three subtests. The classification of outcomes into Risk Category is described in the UFOV manual but we cannot reproduce that information here because the manual is copyright.

2.2.3 Inspection time (IT)

IT stimuli were presented at a viewing distance of 60 cm on the computer monitor with screen resolution 640 x 480 pixels and vertical refresh rate 140 Hz The target figure consisted of two vertical lines, one subtending a visual angle of 2.1 deg and the other 2.5 deg and joined at the top by a horizontal line subtending an angle of 1.2 deg. The shorter line appeared on the left or right equiprobably. The target figure was preceded by a warning cue (small + in the middle of the screen) that lasted for approximately 520 ms. Following exposure of the target figure for the relevant SOA, it was immediately replaced by a “flash” mask (Evans & Nettelbeck, 1993) of approximately 370 ms duration and consisting of two vertical lines subtending a visual angle of 3.3 deg and shaped as lightning bolts (see Figure 1.1). The participant indicated on which side of the target figure the shorter line had appeared, by pressing the corresponding button on the computer mouse.

Instructions emphasised accuracy, not speed of responding. Task requirements were demonstrated on the monitor with unmasked target stimuli. A series of practice trials with masked stimuli then ensured that participants understood what was involved. These required 10 correct trials out of 10 with SOA of 835 ms, 10 correct trials out of 10 with SOA 420 ms and 9 correct trials out of 10 with SOA 250 ms. All of the participants met these criteria. The estimation process began with SOA 250 ms and followed an adaptive staircase algorithm (Wetherill & Levitt, 1965). The algorithm required three correct responses at any SOA before reducing the SOA by 7 ms. When an incorrect response was made the SOA increased by 7 ms. The average SOA was calculated over eight reversals of direction on the staircase, giving an estimate of the SOA with an associated probability of 79 percent of making a correct response.

2.2.4 Crowding Across the Visual Field (CAVF)

CAVF stimuli were presented at a viewing distance of 60 cm on the computer monitor with screen resolution 1280 x 1024 pixels and vertical refresh rate 75 Hz. Stimuli (see Figure 1.2) were displayed for a duration of approximately 130 ms at one of five positions across the horizontal meridian of the display. They were presented at the central fixation point (0 deg eccentricity), 3.3 deg left and right of fixation, and 6.6 deg left and right of fixation, corresponding to locations in foveal, parafoveal and peripheral vision, respectively. Target and flanking stimuli subtended 1.3 horizontal x 1.2 vertical deg of visual angle. Flanking stimuli were located horizontally at 0.4 deg of visual angle on either side of the target. There were twenty target presentations at each of the five possible locations, giving a total of 100 trials for each condition. The order of targets and locations was randomised across trials. Targets were presented under two conditions: unflanked, that is, the target was presented alone; or flanked, where the masking figure was presented horizontally adjacent to the target on both sides of the target figure.

Instructions emphasised the importance of fixating the centre of the screen. Task requirements were explained using very slow presentations of unflanked targets. This was followed by a series of slow practice trials followed by 130 ms duration practice trials (i.e., the same duration as experimental trials). Next, the 100 trials for the unflanked condition were presented. This same procedure was followed for the flanked trials. The rationale was that presenting the trials in this order would mean participants became familiar with the task demands and target figures before undertaking the critical flanked target condition. The number of correct responses at each target position for both conditions was recorded. The correct responses for the left and right parafoveal and left and right peripheral trials were summed. The measures used were the proportion of correct trials for each condition at central, parafoveal, and peripheral target locations. Hereafter these measures will be referred to as Central Unflanked, Parafoveal Unflanked, Peripheral Unflanked and Central Flanked, Parafoveal Flanked and Peripheral Flanked.

2.3 Procedure

The research reported here received approval from the University of Adelaide's Human Research Ethics Committee. All participants provided their informed consent to participate in writing.

Participants attended two sessions at the Cognitive Abilities Laboratory. Upon arrival at the first session, the aim of the study was explained and any questions were answered. First, visual acuity was measured. Next, binocular contrast sensitivity was measured. The room was lit from above with fluorescent light and participants stood one metre from the chart.

Following this, the room was lit with an incandescent lamp so that now there was no overhead light and the background illumination was dim. The remaining tests were completed in the following order: UFOV, IT, CAVF. The total time required for all testing was about one hour.

The second session was held about one week after the first session. At this session all tests except contrast sensitivity and visual acuity were completed in the same order and in the same way as for the first session. Testing time was about 50 minutes for the second session.

3 Results

3.1 UFOV, IT and CAVF measures

The UFOV measures, Risk Category and the threshold estimates for each of the three subtests, which are measured in milliseconds, and the IT measure, also measured in milliseconds, require no comment at this point. The CAVF, being a relatively new measure of strength of crowding in the visual field does require some comment.

Figure 3.1 shows mean proportion of trials correct for each of the target locations for both unflanked and flanked conditions.

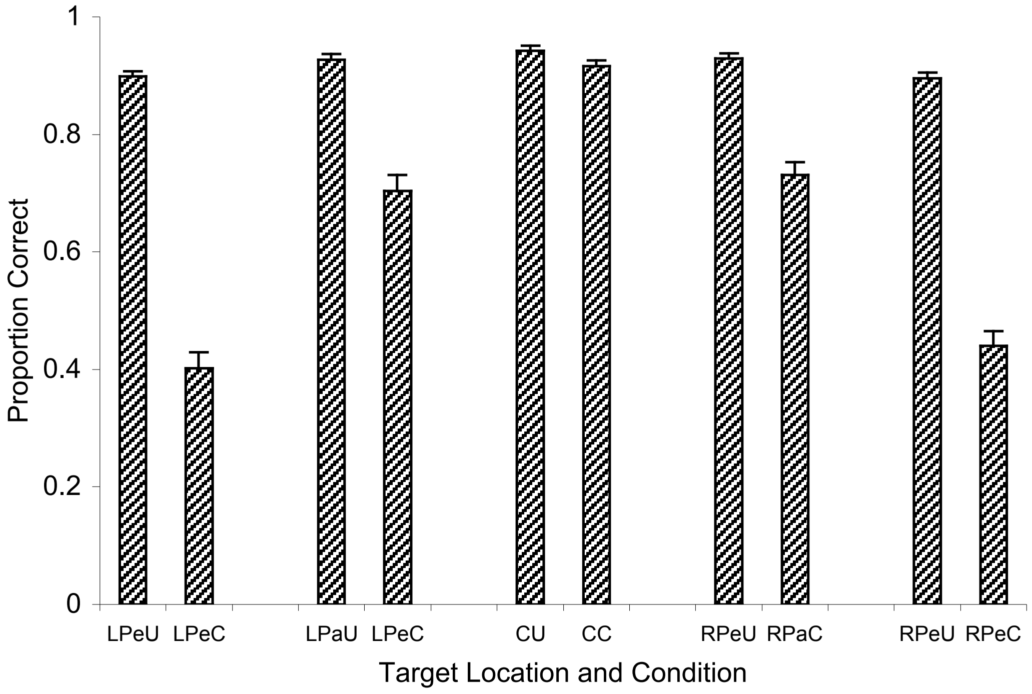


Figure 3.1.

Proportion of trials correct at each target location for Unflanked and Flanked conditions. L = left of central fixation, R = right of central fixation, Pe = peripheral location, Pa = parafoveal location, U = unflanked, C = flanked. CU = central unflanked condition, CC = central flanked condition. Error bars are standard error of mean

It can be seen in Figure 3.1 that performance in the unflanked conditions is very similar across all five locations, although performance does deteriorate when the target is presented parafoveally and even more so when it is presented peripherally $F(4, 56) = 10.5$. $p < .001$, $\eta^2 = .43$. For the flanked conditions, the performance for the central location is slightly poorer than that in the unflanked condition $t(59) = 2.30$, $p = .025$. For the parafoveal and peripheral locations, proportions correct for the left and right locations were averaged. In the parafoveal and peripheral locations performance for the flanked conditions was substantially poorer than for the unflanked condition, $t(59) = 9.3$, $p < .001$ and $t(59) = 21.9$, $p < .001$, respectively. Thus, flanking of the targets in these two locations results in poorer performance. In what follows, the proportion of trials correct for these two locations in the flanked condition will be taken as indexing strength of crowding. The lower the proportion of trials correct, the stronger the effect of crowding on the correct identification of the target.

3.2 Descriptive statistics

Table 3.1 shows descriptive statistics for all measures except visual acuity and contrast sensitivity. Visual acuity had a mean of 0.55 (*SD* = .11)[5] and contrast sensitivity had a mean log contrast of 1.89 (*SD* = .11). Impaired contrast sensitivity is defined as log contrast 1.5 or worse (see Owsley et al., 1998); not one participant had a contrast sensitivity score that met this definition. Moreover, the outcome for contrast sensitivity here is highly comparable with that reported by Edwards, Vance et al. (2005). For their 364 older adult participants, mean log contrast was 1.71 (*SD* = .18). Their study will be considered further in the Discussion (see 4, below).

Table 3.1

Descriptive statistics and test-retest correlations for Useful Field of View (UFOV), inspection time (IT) and crowding across the visual field (CAVF), *N* = 60

	Session 1		Session 2		
	Mean	*SD*	Mean	*SD*	*r*[c]
UFOV[a]					
Processing Speed	18.0	4.31	17.8	3.89	.83
Divided Attention	35.8	24.3	29.2	17.5	.85
Selective Attention	176.8	91.4	160.0	83.6	.89
Inspection Time [a]	67.0	18.2	68.4	20.4	.88
CAVF[b]					
Central Unflanked	.94	.06	.95	0.7	.72
Parafoveal Unflanked	.93	.05	.94	.05	.66
Peripheral Unflanked	.89	.06	.90	.07	.78
Central Flanked	.92	.08	.93	.05	.40
Parafoveal Flanked	.72	.17	.74	.17	.89
Peripheral Flanked	.42	.18	.44	.20	.89

[a] UFOV measures and inspection time (IT) are threshold estimates in milliseconds

[b] CAVF measures are proportion of trials correct

[c] Test-retest correlations; all correlations have associated probability *p* < .001

3.3 Correlations of UFOV with IT and CAVF

The correlation matrix for all variables measured at Session 1 (except contrast sensitivity, see 3.2, above) is at Appendix A, Table A1. Correlations among UFOV, IT and CAVF Parafoveal Flanked and CAVF Peripheral Flanked for Session 1 are shown in Table 3.2.

Table 3.2

Correlations for UFOV, IT and CAVF variables from Session 1, *N*= 60

1. UFOV Processing Speed	1.	2.	3.	4.	5.
2. UFOV Divided Attention	.15				
3. UFOV Selective Attention	-.10	.33			
4. Inspection Time	-.15	.09	.75		
5. CAVF Parafoveal Flanked	.14	-.03	-.79	-.78	
6. CAVF Peripheral Flanked	.17	.04	-.77	-.71	.79

Note. Correlations of .33 and above have associated probability p < .01

Table 3.2 shows the correlations between UFOV, IT, and the two CAVF measures of strength of crowding in peripheral vision (i.e., Parafoveal Flanked and Peripheral Flanked). UFOV Processing Speed and UFOV Divided Attention did not correlate with IT, CAVF Parafoveal Flanked, or CAVF Peripheral Flanked (see 3.5, below). UFOV Divided Attention only correlated with UFOV Selective Attention. Notably, IT and the two CAVF measures

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[5] Visual acuity is expressed here as decimal acuity, the Snellen ratio expressed as a decimal. Thus, the mean acuity here was 0.55 and this is equivalent to a Snellen ratio of about 20/36, or logMAR a little better than 0.3.

correlated strongly with each other. Of most interest is that both IT and the two CAVF measures correlated strongly with UFOV Selective Attention. Correcting these correlations for the reliability of the measures (see Table 3.1) gives the following correlations:

IT and Parafoveal Flanked, $r_{\text{corrected}} = -.88$

IT and Peripheral Flanked, $r_{\text{corrected}} = -.80$

IT and UFOV Selective Attention, $r_{\text{corrected}} = .85$

Parafoveal Flanked and UFOV Selective Attention, $r_{\text{corrected}} = -.89$

Peripheral Flanked and UFOV Selective Attention, $r_{\text{corrected}} = -.87$.

These corrected correlations are so high as to suggest that UFOV Selective Attention, IT, and CAVF crowding are measuring the same phenomenon. This outcome is discussed further below.

3.4 Correlations of UFOV with IT and CAVF: the role of visual acuity and chronological age

Table A1 shows that both chronological age and visual acuity are moderately correlated with UFOV measures, except UFOV Processing Speed, with IT, and with CAVF strength of crowding measures. Tables A2 to A4 show these correlations partialled for age, for visual acuity, and for both age and visual acuity, respectively.

Partialling chronological age from the correlations between UFOV Selective Attention, IT, and the two CAVF strength of crowding measures reduces the zero-order correlations as follows:

IT and UFOV Selective Attention, partial $r_{\text{age}} = .69$

Parafoveal Flanked and UFOV Selective Attention, partial $r_{\text{age}} = -.74$

Peripheral Flanked and UFOV Selective Attention, partial $r_{\text{age}} = -.76$.

Partialling visual acuity from the correlations between UFOV Selective Attention, IT, and the two CAVF strength of crowding measures reduces the zero-order correlations as follows:

IT and UFOV Selective Attention, partial $r_{\text{acuity}} = .54$

Parafoveal Flanked and UFOV Selective Attention, partial $r_{\text{acuity}} = -.74$

Peripheral Flanked and UFOV Selective Attention, partial $r_{\text{acuity}} = -.56$.

Partialling both chronological age and visual acuity from the correlations between UFOV Selective Attention, IT, and the two CAVF strength of crowding measures reduces the zero-order correlations as follows:

IT and UFOV Selective Attention, partial $r_{\text{age/acuity}} = .49$

Parafoveal Flanked and UFOV Selective Attention, partial $r_{\text{age/acuity}} = -.72$

Peripheral Flanked and UFOV Selective Attention, partial $r_{\text{age/acuity}} = -.58$.

Thus, even allowing for the relationship of all these variables with chronological age, visual acuity, or both of them. the correlations between them remain substantial. That is, the relationships between UFOV Selective Attention and IT and the CAVF strength of crowding measures depend partly on chronological age and visual acuity but when these are controlled statistically, the correlations remain substantial and statistically significant.

3.5 UFOV risk category

In this sample, UFOV Risk Category (see 2.2.2, above) at the first testing session was dichotomous with 45 participants being Category 1 (Very Low) and 15 participants being Category 2 (Low). At the second testing session the corresponding data were 55 participants in Category 1 and 5 participants into Category 2; no participant was classified as Category 1 at Session 1 but Category 2 at Session 2. Examination of correlations between UFOV Risk Category and the other UFOV measure showed that UFOV Divided Attention was the main determinant of UFOV category (r = .74). This was confirmed using logistic regression which showed that UFOV Divided Attention alone correctly classified 96 per cent of cases in Category 1 and 75 percent of cases into Category 2. Adding UFOV Processing Speed to the logistic regression model allowed all cases to be correctly classified. A model with UFOV Divided Attention and UFOV Selective Attention did no better than the UFOV Divided Attention alone model. For reasons discussed below (see 4.4) this outcome may not generalise to other samples.

3.6 Distribution of UFOV measures

The distributions of UFOV Processing Speed and UFOV Divided Attention are of concern in interpreting the pattern of relationships observed in these data. For UFOV Processing Speed, 85 per cent of participants attained the minimum possible score, 16.7 ms, that is the minimum duration for which the target could be displayed before it was masked (i.e., one vertical refresh of the display screen); only three participants had scores greater than 30 ms. Thus, this measure behaves almost as a constant in most analyses. UFOV Divided Attention is highly positively skewed (skewness = 1.36, Z = 4.39, p < .001), with a mean of 35.8 ms and a median of 22.2 ms. As an example of the problems these measures cause in data analyses and interpretation, consider Figure 3.2 which shows a scatterplot depicting the relationship between UFOV Processing Speed and IT.

Clearly, there can be no correlation between these variables because UFOV Processing Speed exhibits a pronounced floor effect. Therefore the expectation that UFOV Processing Speed and IT would share substantial variance cannot properly be addressed. This point is taken up further in the Discussion, below.

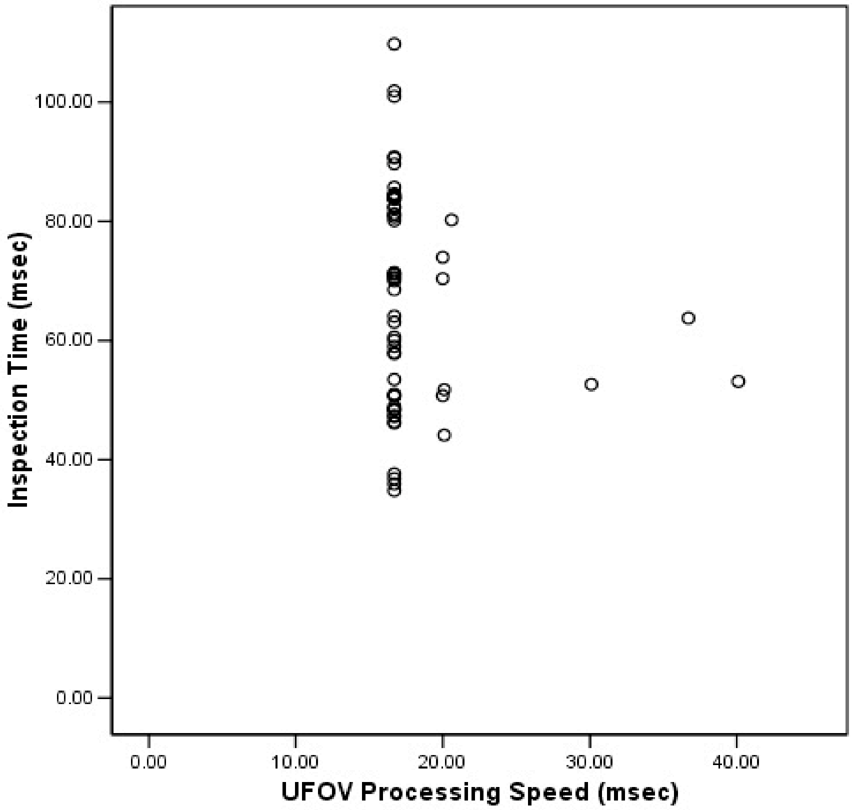

Figure 3.2.

Scatterplot showing relationship between UFOV processing speed and inspection time (IT).

3.7 Comparison of performance across session 1 and session 2

Table 3.3 shows the results of comparing performance on measures across the two testing sessions. (The actual scores in both sessions can be seen in Table 3.1).

Table 3.3

Comparison of performance across session 1 and session 2 for all measures

	Mean Difference[c]	*t*(59)	*p*
UFOV[a]			
Processing Speed	0.2	.50	.62
Divided Attention	6.7	3.88	<.001
Selective Attention	16.8	3.12	.003
Inspection Time [a]	-1.4	1.12	.27
CAVF[b]			
Parafoveal Flanked	.020	1.88	.065
Peripheral Flanked	.014	1.16	.25

[a] UFOV measures and inspection time (IT) are threshold estimates in milliseconds

[b] CAVF measures are proportion of trials correct

[c] Differences were calculated so that a positive number indicates improved performance at Session 2

There were strong practice effects for the UFOV measures (but note that there was no room for improvement on UFOV Processing Speed) but not for either IT or the CAVF strength of crowding measures. This outcome is discussed further below.

4 Discussion

The Useful Field of View test (UFOV) was developed on the basis of research by Ball and colleagues (Ball et al., 1988, was the initial paper in this program). This research, most of it by the developers of the test, has appeared in the peer-reviewed literature over the last seventeen years. The research program has covered aspects including case-control studies on prediction of crash involvement of older drivers; relationships with cognitive function including activities of daily living; and aspects of perceptual function, including speed of processing. The UFOV test has developed to the stage where it is now commercially available as a robust software package for the PC. The test is currently being evaluated under an AUSTROADS program for potential inclusion as part of a fitness to drive assessment in Australian jurisdictions.

The current study compared performance by older drivers on UFOV with their performance on a measure of processing speed that has been studied extensively for the last 30 years, inspection time (IT), and with performance on a newly developed measure of the strength of crowding in peripheral vision, Crowding Across the Visual Field (CAVF). Both IT and CAVF were developed by researchers at the Department of Psychology, University of Adelaide. Because the three UFOV subtests have as their dependent measure an estimate of stimulus onset asynchrony (i.e., the duration between the onset of the target stimulus and a noise mask), measured in milliseconds via an adaptive staircase algorithm, our expectation was that IT would share substantial variance with all UFOV subtests. Because CAVF indexes crowding in foveal, parafoveal and peripheral vision and because UFOV Subtest 3, Selective Attention, uses distractors in parafoveal and peripheral vision that flank the target to be localised, it was expected that CAVF crowding indices would share variance with UFOV Subtest 3, Selective Attention. No predictions were made on correlations between IT and CAVF crowding indices because it was thought that they measured different aspects of visual performance, temporal aspects for IT and spatial aspects for CAVF.

The primary outcomes here were that the corrected correlation between UFOV Selective Attention and IT was .85; and those between UFOV Selective Attention and CAVF Parafoveal Flanked and Peripheral Flanked were -.89 and -.87, respectively. Thus, we feel encouraged to speculate that CAVF and IT together may well prove appropriate and useful as part of a test of fitness to drive assessment for older drivers. Naturally, we acknowledge that these tests would need to demonstrate predictive validity for crashes in older drivers and that some software development is required to allow their use outside of our laboratory.

Addressed in more detail below are data on the reliabilities of CAVF and IT measures and their relationships with UFOV measures. Comparisons are also made on UFOV data collected here with data from the most recent and relevant publication by the developers of UFOV (i.e., Edwards, Vance et al., 2005).

4.1 Comment on CAVF

Prior to the current study, Corlett and White (2002) was the only report of research on CAVF. Their main findings were that CAVF crowding indices were affected by the degree of eccentricity at which a target was displayed and that this effect was stronger for older participants. The results for performance on the CAVF reported here are similar to those reported by Corlett and White to the extent that the proportion of correct responses decreased from .92 for Flanked Central, to .72 for Flanked Parafoveal, to .42 for Flanked Peripheral. The current study also provided data on the reliability of the critical CAVF measures for strength of crowding in peripheral vision; reliabilities for Parafoveal Flanked and Peripheral Flanked were both .89 for measures taken about one week apart. Thus, CAVF appears to be a reliable and straightforward measure indexing strength of crowding in peripheral vision.

4.2 Comment on IT

There is an extensive literature on IT (see, e.g., Nettelbeck, 2001). Mean IT here was in the range expected and test-retest reliability over about one week was .88. IT has been used previously in applied settings (e.g., Burns et al., 1999) and is currently being evaluated as a biomarker for abnormal cognitive decline (O'Connor, Nettelbeck & Wilson, 2004). The outcomes here suggest IT may also have utility in fitness to drive assessment.

4.3 Comment on UFOV

As discussed above (see 1.4 and 2.2.2), the PC version of UFOV, as used here, has only recently been validated against the so-called standard version (Edwards, Vance et al., 2005). It is of interest to compare the results obtained here with those reported by Edwards, Vance et al. In their Experiment 2, 66 community-dwelling older adults, mean age 71.2 years (*SD* = 7.25) completed the PC version of UFOV using mouse response. The means for Subtests 1, 2, and 3 were 52.5 ms (*SD* = 75.4), 154 ms (*SD* = 151), and 323 ms (*SD* = 143), respectively. Test-retest reliabilities over about ten days were .68, .81, and .85 for the three subtests, respectively. In their Experiment 4, 364 participants with mean age 73.2 years (*SD* = 6.48) completed UFOV. For the PC version using mouse response, the means for Subtests 1, 2, and 3 were 25.0 ms (*SD* = 33.3), 113 ms (*SD* = 129), and 324 ms (*SD* = 135), respectively. Reference to Table 3.1, above, shows that for all three Subtests, means were lower for our sample; these differences are statistically significant. Our sample was younger and less variable in age than those of Edwards, Vance et al., with a mean age 65.1 years (*SD* = 5.95). It is also possible that our volunteers were generally healthier. Test-retest reliabilities here were highly comparable to those reported by Edwards, Vance et al.

4.4 UFOV subtest 1 (processing speed) and subtest 2 (divided attention)

As noted at 3.6, above, UFOV Subtest 1, Processing Speed, did not correlate with IT as predicted. Correlations with all other measures were also near-zero because this measure showed very little variance. More specifically, comparing UFOV Processing Speed with the IT task, the following general observations can be made. The former task is too easy. The targets are high contrast and the mask used is not a patterned mask but instead consists of a full screen where each pixel is either black or white with equal probability (that is, a visual noise mask). Therefore, an image of the target may persist even after the mask has appeared. The use of a vertical refresh rate of 60 Hz also means that the minimum exposure duration for the target is about 17 ms. This should be compared with the IT task where a vertical refresh rate of 140 Hz was used giving a minimum exposure duration of about 7 ms on a task where a true patterned mask is used. The distribution of IT scores can be observed in Figure 3.2 as being much more satisfactory than that for UFOV Processing Speed. We claim on the basis of these results that IT is a superior measure of visual processing speed. The failure to observe high correlations between UFOV Processing Speed and IT is because the former task did not show variance in our sample.

UFOV Divided Attention exhibited less severe restriction in range of scores. It is interesting that in the current sample, UFOV Risk Category appeared to depend heavily on this measure. In a number of studies that have analysed UFOV subtests separately, Divided Attention has been the subtest that most consistently correlated with crash risk and/or cognitive impairment. For example, in a study comparing TBI patients with controls (Fiske et al., 2002), the TBI group had significantly higher scores for Divided Attention ($U = 144$, $p < .001$), while another study on HIV patients found that the Divided Attention and Processing Speed subtests were correlated with crash risk (Marcotte et al., 2004).

4.5 UFOV selective attention, IT and CAVF

Correlations between CAVF Parafoveal Flanked and Peripheral Flanked, IT and UFOV Selective Attention were very high, especially when corrected for unreliability of these measures (i.e., based on test-retest correlation). To an extent, these findings were unexpected. We did expect IT to correlate with UFOV measures but we expected the highest correlation to be with UFOV Processing Speed and lowest with the more complex task UFOV Selective Attention. Because of range restriction of UFOV Processing Speed, the correlation with IT was near zero. On the other hand, we did expect the CAVF crowding indices, Parafoveal Flanked and Peripheral Flanked, to correlate with UFOV Selective Attention because the latter task incorporates flanked targets in peripheral vision. What is unclear is why IT and CAVF measures share such substantial variance. The former task requires temporal segregation of stimuli while the latter depends of spatial segregation of stimuli. It may be that there is an element in CAVF that taps perceptual speed. The CAVF stimuli are presented for a nominal duration of 130 ms; this stimulus duration was chosen to obviate eye movements during the trials. However, given that median IT for the sample was 70 ms and the maximum IT was 110 ms, some participants may have been under time pressure for CAVF trials. Another possible explanation for this unexpected finding is that both IT and CAVF (along with UFOV Selective Attention) are very sensitive to overall perceptual performance. In any case, taken together these outcomes suggest that IT and CAVF together may well prove appropriate and useful as part of an assessment of fitness to drive.

4.6 Chronological age and visual acuity

Obviously, it could be argued that the determinants of perceptual performance referred to above will include chronological age and visual acuity. Indeed, all measures of interest shared variance with chronological age and visual acuity (see Table A1). However, when these were statistically controlled, either separately or together, the correlations were scarcely affected and the above conclusions are unchanged. It does appears that whatever reason accounts for UFOV Selective Attention, IT, and CAVF Parafoveal Flanked and Peripheral Flanked correlating highly together, it is largely independent of chronological age and visual acuity.

4.7 Practice effects

An interesting suggestion in the literature on UFOV is that repeated exposure to the tasks leads not only to improvement on performance of the tasks themselves but is accompanied by improvements on everyday functions as assessed, for example, by the Timed Inventory of Activities of Everyday Living (Timed IADL, see Edwards, Wadley et al., 2005). In the Edwards, Wadley et al. study, there was improvement seen on UFOV and Timed IADL with practice. However, improvement did not generalise to other cognitive and performance tasks. Burns, Nettelbeck, McPherson & Stankov (submitted) have shown improvement for IT over 16 threshold estimations and discussed this improvement in terms of the phenomenon perceptual learning. Previously, there was no evidence on learning for CAVF performance indices. The data in Table 3.3 show that there was statistically significant improvement for UFOV Divided Attention and Selective Attention over two administrations separated by about one week, whereas IT and CAVF exhibited weaker and nonsignificant practice effects. In terms of utility as fitness to drive tests, this outcome reinforces the suggestion made at 4.5. This is because IT and CAVF may be more resistant to short-term practice effects than UFOV.

4.8 Conclusion and comment

The overall aim of this study was met. Thus, this study has contributed to an understanding of the processes involved in performance on UFOV, a test of current interest to road safety researchers in Australia. As well as measuring processing speed and aspects of attention as argued by, for example, Edwards, Vance et al. (2005), the Selective Attention subtest also measures crowding in peripheral vision. We therefore feel confident in arguing that the possible utility of IT and CAVF as measures of fitness to drive is worth further exploration. Relationships established here should be explored in a sample of older adults who show relevant deficits; the sample here was obviously low risk. A program exploring the utility of these measures is easy to envisage.

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Appendix A

Table A1
Correlations for age, visual acuity, inspection time (IT), crowding across the visual field (CAVF) and useful field of view (UFOV) at the first testing session (N = 60)

1. Age	1	2	3	4	5	6	7	8	9	10	11	12
2. Visual Acuity	.35**											
3. Inspection Time	.42**	-.62**										
4. CAVF Peripheral Unflanked	-.34**	-.06	-.44**									
5. CAVF Parafoveal Unflanked	-.42**	-.27*	-.13	.66**								
6. CAVF Central Unflanked	-.20	-.04	-.21	.52**	.57**							
7. CAVF Peripheral Flanked	-.32*	.65**	-.71**	.37**	.13	.30*						
8. CAVF Parafoveal Flanked	-.40**	.49**	-.78**	.41**	.10	.10	.79**					
9. CAVF Central Flanked	-.25	.42**	-.64**	.19	-.01	.17	.32*	.53**				
10. UFOV Classification	.52**	-.25	.06	.18	.10	.28*	.22	-.02	-.17			
11. UFOV Processing Speed	-.15	-.13	-.15	.31*	.22	.26*	.17	.14	.07	.43**		
12. UFOV Divided Attention	.57**	-.32*	.08	.12	.03	.17	.04	-.03	-.02	.74**	.15	
13. UFOV Selective Attention	.58**	-.76**	.75**	-.26*	-.01	-.05	-.77**	-.79**	-.46**	.24	-.10	.33**

* p < .05, ** p < .01

Table A2
Correlations for visual acuity, inspection time (IT), crowding across the visual field (CAVF) and useful field of view (UFOV) partialling age

1. Visual Acuity	1	2	3	4	5	6	7	8	9	10	11
2. Inspection Time	-.56**										
3. CAVF Peripheral Unflanked	-.20	-.35**									
4. CAVF Parafoveal Unflanked	-.50**	.06	.61**								
5. CAVF Central Unflanked	-.03	-.15	.49**	.55**							
6. CAVF Peripheral Flanked	.61**	-.67**	.29*	-.01	.26*						
7. CAVF Parafoveal Flanked	.41**	-.74**	.32*	-.08	.02	.77**					
8. CAVF Central Flanked	.37**	-.61**	.12	-.14	.12	.26*	.49**				
9. UFOV Classification	-.09	-.20	.44**	.41**	.46**	.47**	.25	-.05			
10. UFOV Processing Speed	-.19	-.09	.28*	.17	.24	.13	.09	.03	.60**		
11. UFOV Divided Attention	-.16	-.21	.41**	.36**	.35**	.28*	.27*	.15	.64**	.29*	
12. UFOV Selective Attention	-.73**	.69**	-.09	.33*	.09	-.77**	-.75**	-.40**	-.10	-.02	.00

* p < .05, ** p < .01

Table A3

Correlations for age, inspection Time (IT), crowding across the visual field (CAVF) and useful field of view (UFOV) partialling visual acuity

1. Age	1	2	3	4	5	6	7	8	9	10	11
2. Inspection Time	.28*										
3. CAVF Peripheral Unflanked	-.38**	-.61**									
4. CAVF Parafoveal Unflanked	-.58**	-.40**	.68**								
5. CAVF Central Unflanked	-.20	-.24	.52**	.61**							
6. CAVF Peripheral Flanked	-.13	-.51**	.54*	.42**	.36**						
7. CAVF Parafoveal Flanked	-.29*	-.70**	.51*	.28*	.10	.72**					
8. CAVF Central Flanked	-.12	-.53**	.24	.12	.17	.06	.41**				
9. UFOV Classification	.48**	-.13	.17	.03	.30*	.52**	.13	-.08			
10. UFOV Processing Speed	-.21	-.29*	.31*	.19	.27*	.33*	.24	.14	.42**		
11. UFOV Divided Attention	.51**	-.16	.11	-.06	.19	.35*	.16	.13	.72**	.12	
12. UFOV Selective Attention	.52**	.54**	-.47**	-.34*	-.03	-.56**	-.74**	-.23	.07	-.31*	.14

* p < .05, ** p < .01

Table A4

Correlations for inspection time (IT), crowding across the visual field (CAVF) and useful field of view (UFOV) partialling both age and visual acuity

1. Inspection Time	1	2	3	4	5	6	7	8	9	10
2. CAVF Peripheral Unflanked	-.56**									
3. CAVF Parafoveal Unflanked	-.31*	.60**								
4. CAVF Central Unflanked	-.20	.49**	.61**							
5. CAVF Peripheral Flanked	-.50**	.53**	.43**	.35**						
6. CAVF Parafoveal Flanked	-.67**	.45**	.15	.04	.72**					
7. CAVF Central Flanked	-.52**	.21	.06	.14	.05	.39**				
8. UFOV Classification	-.31*	.43**	.42**	.46**	.67**	.31*	-.02			
9. UFOV Processing Speed	-.25	.25	.09	.24	.32*	.19	.12	.60**		
10. UFOV Divided Attention	-.36**	.39**	.33*	.35**	.48**	.37**	.22	.63**	.26*	
11. UFOV Selective Attention	.49**	-.35**	-.06	.09	-.58**	-.72**	-.20	-.24	-.24	-.17

* p < .05, ** p < .01