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Visual Processing Speed

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Abstract

Older adults commonly report difficulties in visual tasks of everyday living that involve visual clutter, secondary task demands, and time sensitive responses. These difficulties often cannot be attributed to visual sensory impairment. Techniques for measuring visual processing speed under divided attention conditions and among visual distractors have been developed and have established construct validity in that those older adults performing poorly in these tests are more likely to exhibit daily visual task performance problems. Research suggests that computer-based training exercises can increase visual processing speed in older adults and that these gains transfer to enhancement of health and functioning and a slowing in functional and health decline as people grow older.

Keywords

Visual processing speed; attention; aging; everyday visual tasks; useful field of view

The term "visual processing speed" can be defined as the amount of time needed to make a correct judgment about a visual stimulus. These responses can be made with reference to many types of visual tasks, including detecting the presence of a target, discriminating between targets, recognizing a target as familiar, identifying what a target is, indicating its spatial location, as well as making other types of decisions about visually complex events. The field of visual psychophysics has a long and rich history going back many decades of utilizing response times under various stimulus and task conditions to further our understanding of visual processing mechanisms (Julesz & Schumer, 1981, Neisser, 1964, Neisser, 1967, Sternberg, 1969, Treisman & Gelade, 1980). As we will see below, measuring visual processing speed as a technique for assessing vision in clinical research has its most direct roots in the field of gerontology, although those who have developed such tools have certainly drawn from the basic visual psychophysics literature.

Several decades ago Birren (Birren, 1965, Birren, 1974) noted that the performance speed of many types of behaviors, including visual behaviors (Kline & Birren, 1975), were often slowed in older adults, leading him to characterize slowing as one of the most robust behavioral phenomena of human aging (Birren & Fisher, 1991). Salthouse (e.g., Salthouse, 1991, Salthouse, 1995, Salthouse, 1996, Salthouse, 2004, Salthouse, 2005) observed that

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deficits in many cognitive domains (e.g., working memory, visual attention, associative learning, executive function) in older adults otherwise in good health (i.e., free of diagnoses of dementia) were closely associated with a slowing in perceptual processing speed, leading him to suggest that a generalized slowing in information processing was responsible for many aging-related cognitive impairments. However, research also suggested that aging-related slowing in perceptual and cognitive tasks is not ubiquitous in that whether older adults exhibit slowing depends on many factors such as task demands, stimulus configurations, consistency of response, as well as practice (Anstey, Hofer & Luszcz, 2003, Ball et al., 1988, Cosman et al., 2012, MacDonald, Hultsch & Dixon, 2003, Madden, 2001, Sekuler & Ball, 1986). There are also wide individual differences in the older adult population in visual processing speed. For example, a population-based study on 2,000 older adults found that some exhibited duration thresholds similar to young adults in a visual discrimination task, while others exhibiting seriously elevated duration thresholds (Owsley, McGwin & Searcey, 2012 in press).

Sekuler and Ball (Sekuler & Ball, 1986) observed that many older adults describe everyday visual task difficulties in situations that involve visual distractions or clutter (e.g., finding a face in a crowd) or the need to divide visual attention (e.g., driving), especially under time sensitive conditions, which is also supported by questionnaire studies (Ball, Owsley & Beard, 1990, Kosnik et al., 1988, Sloane et al., 1992). These visual performance problems could not be attributed to visual sensory deficits such as impairments in visual acuity or contrast sensitivity or loss of light sensitivity in the visual field; even older adults in good visual health and with normal visual sensory function reported these task challenges. Sekuler and Ball (Sekuler & Ball, 1986) sought to understand the visual mechanisms underlying these daily task problems and developed a laboratory analog. This task involved a center task and a peripheral task. The center task was presented in the central field at fixation and involved the discrimination of two targets. The peripheral task consisted of the radial localization of another target simultaneously presented in the peripheral field at 5°, 10°, or 15° eccentricity, which could be either presented among no distractors or with distractors present. A key aspect of the task was that stimulus displays were presented at very brief durations (125 ms) in order to challenge the observer’s processing abilities, since the previous gerontological literature mentioned above indicated that older adults often have slowed information processing speed. Task performance was assessed in terms of errors when the central task was presented alone, and when the central and peripheral tasks were presented together. Sekuler and Ball (1986) demonstrated that when observers were only required to identify the central target, both young and older adults performed similarly. However when also required to specify the radial location of a peripherally presented target out to 15°, older adults showed decrements in performance, which were further exacerbated when targets were presented among visual distractors. They also found that age differences were greater as the peripheral target was located at greater retinal eccentricities. They concluded their paper by stating that “clinical tests of vision, which minimize distractions, may give unrealistic estimates of the vision available to the elderly under real-life conditions, where visual distractions may be the rule rather than the exception” (p. 867, Sekuler & Ball, 1986).

Ball, Roenker, and colleagues (Ball et al., 1988, Ball, Roenker & Bruni, 1990) further pursued the development of a visual processing test that incorporated divided attention and visual distractors under brief stimulus conditions by studying what they termed the “useful field of view”. They drew on prior work by Sanders (Sanders, 1970) on the “functional field of view” and also Verriest et al. who used the term “occupational field” (Verriest, 1983, Verriest, 1985). Ball and Roenker defined the useful field of view as the spatial area over which useful information can be acquired rapidly without the use of eye or head movements (within one fixation). Although other researchers did not refer to this phenomenon as “the useful field of view" per sé, their body of work indicated that the useful field of view is not fixed in size but depends on the situation (stimulus configuration and task demands). For example, size of the useful field of view depends on the presence of a foveal stimulus, a more or less difficult task to perform at fixation, the presence or absence of visual distractors, and the distractor's similarity to the target of interest (Bergen & Julesz, 1983, Bloomfield, 1972, Drury & Clement, 1978, Engle, 1977, Ikeda & Takeuchi, 1975, Leibowitz, Myers & Grant, 1955, Treisman & Gelade, 1980, Williams, 1982). Its size also is influenced by age; compared to younger adults, older adults' performance is more likely to be hampered by brief stimulus presentations, the addition of secondary tasks, and distractors (Ball et al., 1988, Cerella, 1985, Edwards et al., 2006, Plude & Hoyer, 1985, Rabbitt, 1965, Scialfa, Kline & Lyman, 1987, Sekuler & Ball, 1986).

Interest in the useful field of view as a clinical assessment tool has been stimulated by the many studies finding that older adults who perform poorly in a useful field of view task are more likely to experience difficulties in visual tasks of everyday living. Older drivers with impaired useful field of view performance are at an elevated risk for motor vehicle collision involvement (Ball et al., 1993, Ball et al., 2006, Cross et al., 2009, Owsley et al. 1998, Owsley et al., 1991, Rubin et al., 2007) and are more likely to exhibit impaired on-road or simulated driving performance (Clay et al., 2005, Rizzo et al., 1997, Wood, Dique & Troutbeck, 1993). Useful field of view deficits in older adults are also associated with a host of other problems in the activities of daily living including performance mobility deficits (Owsley & McGwin, 2004), limitations in the extent of travel into one's community (Stalvey et al., 1999), reduced participation in physical activity (Roth et al., 2003), an increased falls risk (Sims et al., 1998), reduced household activity (Sims et al., 2000), and increased time needed to perform visual tasks of everyday living (e.g., reading a prescription bottle, finding an item on a shelf) (Edwards et al., 2005b, Owsley et al. 2001, Owsley et al., 2002). This large body of work has also indicated that these useful field of view associations with task performance problems remain even after adjustment for visual sensory deficits and aging-related cognitive impairment.

Over the years Ball and Roenker's research group has refined the characteristics of the useful field of test and methods of scoring (summarized in Edwards et al., 2006, Edwards et al., 2005a). An early version of the useful field of view task (Ball & Owsley, 1993, Ball et al., 1993) involved three subtests involving high contrast stimuli (99%) presented at photopic luminance, with both central and peripherally presented targets subtending a relatively large visual angle (~ 5° × 3°). Stimulus displays were presented for 16.67 to 250 ms. The center task targets were designed to be visible and discriminable to even persons with minor visual impairment, i.e. visual acuity as low as 20/70 acuity and light sensitivity in the Humphrey Field Analyzer as low as 15 dB (Owsley, Ball & Keeton, 1995). Subtest one consisted of a center task only where the observer was simply asked to discriminate whether the target presented at fixation was a cartoon of a car versus a truck. Performance was evaluated in terms of the minimum stimulus display duration at which the observer could correctly perform the center task 75% of the time. Subtest two involved the same center task but also presented simultaneously a peripheral target; the observer was asked to not only perform the center task but also indicate the radial direction of the peripheral target. The peripheral target could be located at 10°, 20°, or 30° degrees eccentricity along any of 8 radial directions. Subtest three was identical to subtest two except now the peripheral target was presented such that it was embedded in distracting stimuli. For subtests two and three, the best fitting line reflecting the relationship between eccentricity and localization errors was first computed for each test duration, and the size of the UFOV was defined for that stimulus duration as that eccentricity at which the subject could localize the peripheral target correctly 50% of the time. Performance in each of the three subtests was then scaled, in each case along a stimulus duration continuum, to arrive at three scores representing the extent of difficulty with respect to speed of processing, divided attention, and selective attention (corresponding to subtests one, two, and three, respectively). These scores ranged from 0 (no problem) to 30 (great difficulty) and represented the extent to which the useful field of view of the 30° radius field was constricted in size. Details of the scoring methods are provided in (Edwards et al., 2005a). One downside to the original version of the useful field of view test was that it took up to 30 minutes to administer.

In recent years Ball and Roenker and colleagues have developed a commercially available software version of the test called UFOV® (Visual Awareness Research Group, Punta Gorda FL) that is designed for use on a personal computer with a touch-screen or a mouse (Edwards et al., 2006, Edwards et al., 2005a). Many of the basic test characteristics remain from the original version, however there are some changes. A major change is the metric used to characterize performance. Performance in each of the subtests (center task only, center task plus peripheral localization, center task plus peripheral localization when target is embedded in distractors) is no longer characterized as the spatial area in the 30° radius visual field over which an observer can rapidly process visual information; that is, the amount of reduction or constriction in the field is not the test's output, as before. Rather, performance in the current UFOV® software is defined as an observer's minimum duration for correct central task performance 75% of the time for each of the subtests; thresholds can range from 16.67 to 500 ms. Thus, visual processing speed, i.e. the stimulus duration threshold, is how test performance is now characterized. There is also a fourth subtest in the UFOV® test software that is similar to the third subtest except the discriminability of the targets in the central task is more difficult. Peripheral targets are presented at ~10° eccentricity along any of 8 radial directions as in the original test, but not at further eccentricities. It is important to point out that the UFOV® test is in good agreement (0.658 to 0.746) (Edwards et al., 2005a) with the original test version used in many of the studies documenting its relation to everyday visual task performance (Ball et al., 1993, Owsley et al., 1998, Owsley & McGwin, 2004, Owsley et al., 2001, Owsley et al., 2002, Roenker et al., 2003, Rubin et al., 2007). The UFOV® test is also briefer than the original version, and can be completed in ≤ 15 minutes. The test-retest reliability of the UFOV® test is estimated to be between .735 and .884, depending upon whether one uses the touch-screen or mouse response modality, which are also in good agreement with each other (0.916) (Edwards et al., 2005a).

Several research groups have explored possible mechanisms underlying older adults' slowed visual processing speed in useful field of view tasks. Using the UFOV® software, Cosman and colleagues (Cosman et al., 2011) found that those older adults with slowed visual processing speed in subtests involving central target discrimination and peripheral target localization (subtests 2–4) tended to also have problems with attentionally disengaging from a cued location. Earlier work has also highlighted aging-associated problems with disengaging and shifting attention (Castel et al., 2003), although this work did not specifically focus on useful field of view tasks. Other researchers have suggested that useful field of view task difficulties stem from inefficiencies in visual processing and visual search, thereby slowing processing speed, which thus increases the time needed to complete the task (Cosman et al., 2012, Lunsman et al., 2008, Owsley, Burton-Danner & Jackson, 2000, Seiple et al., 1996, Sekuler, Bennett & Mamelak, 2000, Vance et al., 2007). A growing body of work suggests that older adults' fundamental problem in performing useful field of view tasks does not stem from a constriction or shrinkage in the size of the attentional or functional field as originally suggested (Ball et al., 1988), but is more likely due to inefficiencies in visual search and problems with attentional disengagement, which in turn slow the visual processing time needed to complete the task at hand. Thus the evolution in the UFOV® metric from the "size" of the useful field of view (as in the original work) to a visual processing speed metric (i.e., minimum duration threshold), as in the latest software, is well supported by the basic research.

Ratcliff and colleagues (e.g., Ratcliff, Spieler, & McKoon, 2000; Ratcliff, Thapar, & McKoon, 2001) have argued that older adults' increased time needed to complete visual tasks is more properly attributed to differences in speed-accuracy trade-off compared to young adults, than to a generalized slowing in processing speed. In this framework, older adults have longer response times when making decisions about visual targets because they are more concerned about accuracy and thus have a more cautious or conservative approach, operationalized as taking more time to make a decision and respond. While speed-accuracy trade-off differences between young and older adults may contribute to slower response times in older adults in laboratory paradigms where reaction time is the dependent measure, it is difficult to see how it would account for laboratory tasks such as the UFOV task where reaction time is not the dependent measure under study. In the UFOV paradigm, as described above, stimulus duration thresholds are measured. During a double staircase procedure, the visual test display is presented at various durations. The subject's task is to identify the central target, or to state whether the central targets are same or different (depending on the specific subtest). The subject can take as long as they want to respond. A duration threshold, not a response time, is the dependent measure.

A question that arises is whether an older adult's visual processing speed can be improved, i.e. "speeded up". Sekuler and Ball (Ball et al., 1988, Sekuler & Ball, 1986) began to lay ground work in the 1980s showing that older adults' percent correct in a peripheral target localization task while also performing a centrally presented target discrimination task, all under brief target durations (90 or 125 ms), improved during daily sessions over several days or months; this improvement was still enduring up to six months later. This implied that practice led to an improved efficiency of visual processing. In several subsequent studies (Edwards et al., 2002, Edwards et al., 2005c, Roenker et al., 2003, Vance et al., 2007, Wadley et al., 2006) including a randomized, multi-site clinical trial sponsored by the National Institutes of Health (Ball et al., 2002, Willis et al., 2006), a training program based on the UFOV® tasks leads to reductions in minimum duration thresholds, i.e., visual processing was "speeded up", and that these training benefits were still manifest up to two years later. The practice or training program used in these studies, detailed in (Ball, Edwards & Ross, 2007) and briefly summarized here, involves an observer engaging in practice on the UFOV® computer administered tasks. Initial display durations are tailored to the ability of the observer; trial-by-trial feedback is provided as well as feedback on the number of trials correct at the end blocks of 16 trials. A trainer encourages continued practice over blocks of trials and sessions and potential strategies for enhancing performance until criterion levels of performance are achieved; however a "home-based" training program on one's own PC has also shown to have efficacy (Wadley et al., 2006). After a criterion level of performance is reached, the stimulus display duration on the subsequent blocks is reduced. Once a criterion level of duration threshold is reached on a specific task, then the task difficulty is increased (e.g., a central discrimination task with a concurrent radial localization task is made more difficult by the addition of distractors). The ultimate goal of training is to improve processing speed (reduce minimum duration thresholds for task performance) by slowly decreasing display duration until a criterion level of performance is met.

Considerable research, much of it from randomized intervention trials, has shown that visual processing speed training as described above can have positive impacts on the health and functional well being of many older adults. For example, increases in processing speed in older adults have lead to reductions in motor vehicle collision risk (Ball et al., 2010), improved on-road driving performance (Roenker et al., 2003), decreased reaction time to road signs (Roenker et al., 2003), reduced time to perform common visual activities of daily living (locating an item on a grocery shelf, reading ingredients on a food package) (Ball et al., 2002, Edwards et al., 2005b), slowing of reductions in health-related quality over 24 months (Wolinsky et al., 2010), and reduced risk of depression (Wolinsky et al., 2009a, Wolinsky et al., 2009b). Who among older adults are most likely to benefit from speed of processing training? Those most likely to benefit are those who demonstrate slowing (elevated duration thresholds) at baseline, i.e. they have room for improvement (Ball et al., 2007). Educational level has no impact on training gains (Ball et al., 2007). Although Leat and Lovie-Kitchin (Leat & Lovie-Kitchen, 2006) have shown that it is possible to measure the useful field of view in patients with low vision, it remains to be determined to what extent visually impaired older adults can benefit from visual processing speed training, even if stimulus configurations were large enough so that they were visible to those with vision impairment. The efficacy of speed of processing training for those with mild cognitive impairment (MCI) has not yet been determined, although there is some evidence that those with memory deficits consistent with MCI may benefit from the training, i.e. they exhibit improvements in speed of processing (Unverzagt et al., 2007). MCI is often viewed as a transitional state from normal cognitive aging to Alzheimer's disease and other forms of dementia (Flicker, Ferris & Reisberg, 1991, Morris et al., 2001).

To conclude, clinical vision tests are largely focused on visual sensory abilities, such as visual acuity, contrast sensitivity, light sensitivity in the visual field, and color vision. Yet many visual complaints and symptoms reported by older adults in their visual tasks of everyday living cannot be attributed to visual sensory impairments. Several decades of research suggest that slowed visual processing speed, especially under conditions of divided attention and visual clutter, is common in older adults, which can negatively impact their visual task performance in everyday life. Progress has been made in recent decades in designing valid and reliable methods for assessing visual processing speed in the clinic or laboratory. Training interventions to speed up visual processing have also been shown to be efficacious in some older adults, with ensuing generalized benefits to health and functioning.

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Highlights

- Elderly cite difficulty in tasks involving visual clutter and secondary tasks demands
- These difficulties often cannot be attributed to visual sensory impairment
- Techniques exist for measuring visual processing speed under these conditions
- Those who perform poorly in tests are more likely to exhibit daily task problems