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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.

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, 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 (1965, 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 (1991, 1995, 1996, 2004, 2005) observed that 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, and 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 2000 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 et al., 2012).

Sekuler and 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 (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

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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" (Sekuler & Ball, 1986, p. 867).

Ball, Roenker, and colleagues (Ball, Roenker, & Bruni, 1990; Ball et al., 1988) 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 (1970) on the "functional field of view" and also Verriest et al., who used the term "occupational field" (Verriest, 1983, 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, 2006; Cross et al., 2009; Owsley et al., 1991, 1998; 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, Wadley, et al., 2005; Owsley et al., 2001, 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) and Edwards, Vance, et al. (2005)). 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 ($\sim 5° \times 3°$). Stimulus displays were presented for 16.67–250 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° eccentricity along any of eight 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, Vance, et al. (2005). One downside to the original version of the useful field of view test was that it took up to 30 min 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, Vance, et al., 2005). 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