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Real-world evaluation of visual function

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Many older adults will ultimately experience some degree of decline in their ability to see and process visual information, which can have a negative impact on their performance of daily visual activities and their quality of life. Given the widely recognized trend in recent decades toward increased longevity, maintaining functional abilities into older age is of critical importance. Therefore, those substantial investments in medical research and healthcare that have produced gains in length of life must now be supplemented with equal investments in strategies and technologies that assess and improve the kinds of visual function necessary for autonomous functioning.

Assessment of visual function in older adults

Ophthalmologists are frequently called on to evaluate the functional status of the visual system in terms of what activities an individual may engage in and to diagnose the presence of disease. This may prove a difficult task because there is often a mismatch between sensory loss and the ability to function in the world—some persons with dramatic losses function well, whereas others with only minor sensory loss report great difficulty in visually guided activities. This difficulty may be exacerbated in the older population, in whom there is a marked increase in the range of functional abilities and often no clear distinction between aging and early onset of disease.

Visual function is typically evaluated clinically by having the patient read a letter chart or respond to visually presented targets. These methods rely on the observer's subjective report of what is or is not seen. Another contributing factor to the difficulty of assessing older adults is that the elderly tend to be reluctant to say that they detect a target unless they are sure [1]. This reluctance can cause the appearance of greater visual impairment in older persons than in younger ones. In other words, older persons tend to adopt a more stringent criterion and will not report that an object is seen, or read farther down a letter chart, unless the sensory evidence is extremely strong. Younger people, on the other hand, are more likely to guess and may appear to have a lower sensory threshold or better visual function. If typical testing methods are to be used, it is critical that older patients be encouraged to continue to read a letter chart or to respond even when they are unsure of what they see. On the other hand, more objective forced-choice testing can be used in which the patient must "prove" that he or she can see a stimulus. This can be done, for example, by having the patient identify a light's position rather than simply its presence or by identifying the orientation of a target. Using this testing approach, it is typically found that stimuli can be discerned at intensities far lower than the thresholds determined by more subjective methods. Thus, many studies indicating age-related vision decline may overestimate the sensory contribution to age differences. Even so, when aspects of vision are evaluated with clinical or laboratory-based measures, visual function is shown to decline in later life, even for persons who, according to standard clinical practice, have good eye health.

This is not to say, however, that age-related declines observed in a clinical or laboratory environment necessarily affect everyday visual tasks performed in the real world. There is, for example, a consider-

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able difference between someone's ability to perform a visual acuity test in a laboratory under optimal conditions and the ability to walk without falling, drive a vehicle, or recognize a friend in a crowd. Therefore, the study of vision and aging should not only occur under ideal circumstances, it should be evaluated in a context in which the visual demands may be very different and in which the outcomes of assessment could have widespread social and policy ramifications.

Vision and everyday function

There has recently been increasing concern about the relation between visual impairment and functional dependence among older adults. Several large population-based studies have demonstrated that visual impairment is associated with difficulty in performing activities of daily living (ADLs) and the more cognitively demanding instrumental activities of daily living (IADLs). These activities rely on sensory and cognitive abilities. In addition, there is much interest in exploring the interrelationships between vision and cognition among older adults. Studies have shown that even in people with clinically normal vision, age-related declines can be demonstrated in various measures of visual function, including acuity, contrast sensitivity, glare, visual fields, and useful field of view [2]. In addition, acuity, which is typically used to evaluate vision for refractive purposes, is not as strongly related to many everyday activities as was previously believed [3–6]. For example, older adults are at a disadvantage in recognizing faces at lower ambient light levels. They typically need approximately twice the contrast to detect and discriminate between faces than do younger adults. This age-related decline cannot be explained by poor acuity and also cannot be explained on the basis of a stricter threshold criterion [7]. Rather, the best visual correlate of face perception is spatial contrast sensitivity, which is a more sensitive index for the ability to discriminate larger details.

The focus of much recent research in the area of vision and functional abilities has been the development of tasks that are predictive of difficulty in everyday visual activities. In the development of such tasks, the emphasis has been to determine the bases of age-related functional problems and the development of interventions that would potentially reverse or retard further loss of functional ability. With an increasing number of older adults continuing to work and drive, the long-range goal is to identify how visual assessment can be improved to better address older adults' functional vision problems in everyday activities.

One way in which functional independence is evaluated in older adults is with respect to their ability to perform IADLs. These activities involve many domains of everyday life, including reading, driving, cooking, managing finances, shopping, managing one's health care (medications and doctor's appointments), and even social interactions. For many years, IADL functioning was evaluated in older adults through self-report with measures such as the Multilevel Assessment Instrument [8], the SF-36 [9], or the OARS Multidimensional Functional Assessment Questionnaire [10]. Visual function is understandably highly related to IADL performance [11–14], and many instruments that target visual instrumental activities specifically have been developed in recent years [13–18]. Questionnaire measures of vision-specific, health-related quality of life can provide useful information about patients' perceptions of the impact of vision impairment on their everyday lives. Such measures can serve as a supplement to standardized clinical outcomes and the physician's interpretation of these outcomes [19]. The centrality of vision to a quality of life that is subjectively worthwhile is made clear with the use of these measures.

Two primary lessons have been learned from questionnaire research: (1) older adults report visual difficulties that are not adequately identified by standard clinical measures, and (2) older adults are sometimes totally unaware of their visual problems. Consistent with these conclusions, several other studies have shown a mismatch between self-reported abilities and functional measures. For example, Flint et al [72] found no correlation between the amount of self-reported driving by the elderly and their performance on a driving simulation, and no correlation between performance on a vision test and their self-assessed quality of vision. Others [20] have found that many elderly drivers with poor vision are unaware of their problem and continue to drive with reduced vision.

Based on the findings that some older persons do not validly evaluate their everyday abilities [21,22], there has recently been increased interest in developing performance-based tasks of IADLs rather than relying on self-reported IADLs [23]. Specifically, it has been reported that healthy older adults and those with mild cognitive impairment tend to overestimate their functional abilities [22], whereas depressed older adults tend to underestimate their abilities [24]. With respect to visual IADLs, tests of reading performance have been developed [25,26], though these tests have been criticized for not using actual everyday reading materials such as newspapers, magazines, medicine bottles, and so on. For older patients with low vision (acuity of 20/100 or worse), tests have been developed that evaluate performance on tasks such as clock reading, large-text reading, color recognition, and currency discrimination. Alexander et al [27] developed five everyday tasks (reading a large-print magazine, telling time, identifying colored handkerchiefs, identifying common household objects, and recognizing facial expressions) and found that accuracy of performance was related to visual acuity and contrast sensitivity. Turco et al [28] constructed a battery of tasks focused on reading (spot reading, text reading, identifying paper currency, and clock reading), which was associated with near visual acuity. A problem with these prior studies, however, is that associations were not adjusted for the confounding effects of cognitive impairment, depression, and declining general health, all of which are common in older adults and are known to influence older adults' performance of IADLs. Thus, until recently, it remained to be determined whether vision impairment has an independent impact on IADL performance.

Recent studies [29,30] have examined the independent contributions of visual function and cognitive function on IADLs with a newly developed performance-based measure of IADLs. This timed IADL (TIADL) measure assesses IADL task completion time and can be used to evaluate the relation between vision or cognition and speed of successful performance of everyday tasks. In one study, Owsley et al [29] assessed visual acuity, contrast sensitivity, and useful field of view in a sample of 342 older adults recruited from eye clinics. They also administered the TIADL, which includes a variety of visual activities such as reading ingredients on cans of food and instructions on medicine bottles, finding a phone number in the telephone book, and locating items on a crowded shelf. Results indicated that poorer performance on each visual index was independently associated with longer times to complete the visual TIADL tasks, even after adjusting for age, educational level, depression, and general health. Cognitive status was also independently associated with time to complete the tasks. The authors conclude that older adults' timed performance in everyday tasks is related to various aspects of visual function independent of age and of other functional and health problems. The results also highlight the need to account for the role of cognitive function in performance of everyday tasks.

Another recent study attempted to evaluate the extent to which training in the speed with which complex visual information is processed can improve everyday functional performance among older adults [31]. Ninety-seven older adults were administered a battery of tests assessing visual-perceptual ability, speed of processing, and the TIADL test as described above. Forty-four of the participants received 10 hour-long sessions of speed-of-processing training. The remaining participants were in a no-contact control group. Approximately 6 weeks after the pretraining assessment, all participants repeated the same battery of tests. Results revealed significant improvement, as a result of training, in the speed with which instrumental activities of daily living were successfully completed. Thus, the TIADL measure appears to be sensitive to this intervention targeting processing speed, and in the future it may also prove responsive to interventions targeting reversal of vision impairment or minimization of its impact.

Vision and mobility

As previously discussed, intact visual function is central to quality of life. One functional domain that is crucial for maintaining a satisfying quality of life is mobility. Mobility ensures access to social contacts and health care and continued independent functioning. Mobility can be jeopardized, however, with declines in visual function and declines in physical and cognitive functions. Almost 20% of adults older than 65 report having mobility difficulties [32], and these difficulties have been shown to increase the need for formal and informal care [33]. Declining vision may also play a role in the increased prevalence of falls in the elderly [34]. Poor contrast sensitivity is associated with mobility problems, and deficits in temporal processing and motion perception may also contribute to walking difficulty. Thus, there is growing concern that as the percentage of older adults in the population increases in the next 30 years, there will be a concomitant increase in the number of older adults who cannot ambulate independently.

Vision and driving

Driving is a vital means of maintaining mobility in many countries and is, therefore, integral to independence and quality of life. Most older adults in the United States rely primarily upon the personal automobile for maintaining mobility [35]. As people age, however, their driving skills may become compromised or called into question. Driving cessation poses a severe threat to mobility and can lead to negative consequences such as less access to volunteer or employment opportunities, religious and social activities, and health care services [36]. Public concerns for safety and autonomy call for effective evaluation of driving risk, including thorough assessment of relevant visual functions, and proven rehabilitative programs for those at risk.

A considerable amount of information has been collected on the relation between visual decline and driving among older adults. Older drivers have disproportionately more accidents and citations than middle-aged drivers, and their accident profiles include failures to heed signs, to yield the right of way, and to turn safely and an increased prevalence of intersection accidents. Impaired vision is typically thought to be responsible for these types of accidents. However, most of the evidence linking visual sensory decline to driving problems is weak. For example, static visual acuity has consistently been found to have an extremely weak relationship to traffic accidents [37 39]. Obviously, a basic level of visual function is necessary for safe driving. Until recently, many licensing agencies have screened predominantly for visual acuity impairments, but some have required no visual assessment whatsoever for license renewal. In licensing agencies that require the assessment of visual acuity, measurements may vary greatly from having the candidate read an eye chart, many times without strict control of luminance conditions or other important parameters affecting the outcome of testing, to novel computerized assessments.

Originally, visual acuity assessments were designed for clinical use to detect and monitor the progression of disease. Thus, assessment measures were not designed to reflect the visual complexity of driving or other everyday activities [40]. State-of-the-science visual acuity testing has expanded from well-calibrated eye charts to light boxes to, most recently, software programs that may have distinct advantages for driver licensure. For example, automated vision tests can improve efficiency in heavy-volume settings by eliminating the need for one-on-one manual testing. Results with computerized tests are automatically scored and saved, reducing personnel time and the possibility of transcription errors. Automated vision tests may also be integrated with other functions at a licensing agency such as knowledge-based testing, digital photograph capture, and biometric recognition systems. Furthermore, randomized test designs make vision test memorization impossible. Because test results are automatically stored, they can be easily integrated into existing data management systems, and changes and trends in each patient's vision can be saved and flagged if substantial visual decline is noted. Finally, automating the visual acuity test has the potential to enable licensing agencies to test far more than visual acuity, possibly adding other visual or cognitive test measures that are predictive of driving competence, thereby improving the overall assessment process. Although vision test software is still relatively new, companies that market professional vision assessment software are beginning to gain acceptance in license agency settings.

Despite these technological advances in the measurement of vision, evidence generally suggests that traditional tests of vision such as visual acuity and disability glare are either not independently predictive of crash involvement [41 44] or are only weakly related [3,40,45]. For several reasons one might expect not to find a strong relation between visual acuity and driving. Good acuity may be helpful when the vehicle is stopped or is moving slowly, but it is of less benefit when driving at normal speeds. Dynamic visual acuity, however, is also only weakly related to measures of driving performance. Furthermore, unlike real visual scenes that vary in complexity, contrast, and illumination, the stimuli used to measure visual acuity are small, of high contrast, and of low complexity.

Several recent studies have also included contrast sensitivity as a predictor of driving ability. These studies have shown that though it was a slightly better predictor than acuity, the strength of the relationship was still relatively weak [3]. Visual function measures such as contrast sensitivity and visual field sensitivity may be better predictors of crash involvement than visual acuity, but, even so, the relations are relatively weak [40,43,45,46]. An exception was found in a large sample study (N = 10,000) by Johnson and Keltner [46], who observed that a small subset of older drivers with severe binocular field loss had crash and conviction rates twice as high as those with normal visual fields. These results were confirmed in another study [3], though in general, the correlation between crash frequency and visual field sensitivity was weak.

For night driving, the eye must accommodate to many levels of illumination because of headlights from other vehicles and almost complete dark adaptation in low traffic or un-illuminated roadways. Henderson and Burg [38], however, found no relation between low illumination static acuity and crash rate, and Burg [47] found no relation between dark adaptation and crash involvement. Similarly, Owsley et al [44] found an insignificant relation between acuity measured under low illumination and crash rate.

Because driving involves complex visual information processing abilities, it is unlikely that an assessment of visual function alone is sufficient to identify most persons at elevated risk for crash involvement. Driver inattention and deficiencies in visual information processing have also been proposed as factors in accident causation [48]. Treat et al [49] suggested that hazard recognition errors be interpreted more as attention failures than as sensory deficiencies. Consistent with this interpretation, it has been found that the useful field of view (discussed in greater detail in "Useful field of view" below) is a better predictor of crash involvement than all visual sensory function measures combined [50].

Useful field of view

As mentioned, another approach to examining the visual field is to assess the functional or useful field of view, which involves the localization and identification of complex visual stimuli in the periphery [51,52]. The concept of the useful field of view was originally described by Sanders [51], who used the term "functional visual field" to define the visual field area over which information can be acquired in a brief glance without eye or head movements. Increasing restrictions in the useful field of view are depicted graphically in Fig. 1. The term useful field of view was first used by Ball et al [71] and subsequently has come to be most widely known as a specific test administered on a computer with touch screen technology (UFOV® test; Visual Awareness, Chicago, IL). Although standard visual field testing as described above seeks to minimize environmental factors typical of everyday situations, assessment of the useful field of view includes features designed to mimic everyday visual activities, such as complex visual scenes with distracting stimuli and simultaneous use of central and peripheral vision (Fig. 2).

The concept of the useful field of view and its measurement were further refined as research in the area of visual information processing progressed during the 1980s and 1990s. For instance, research demonstrates that the diameter of an area that can be searched serially [53] or in parallel [54] is directly related to target/distractor similarity (conversely known as conspicuity) and stimulus duration. In other words, more conspicuous targets are recognized at

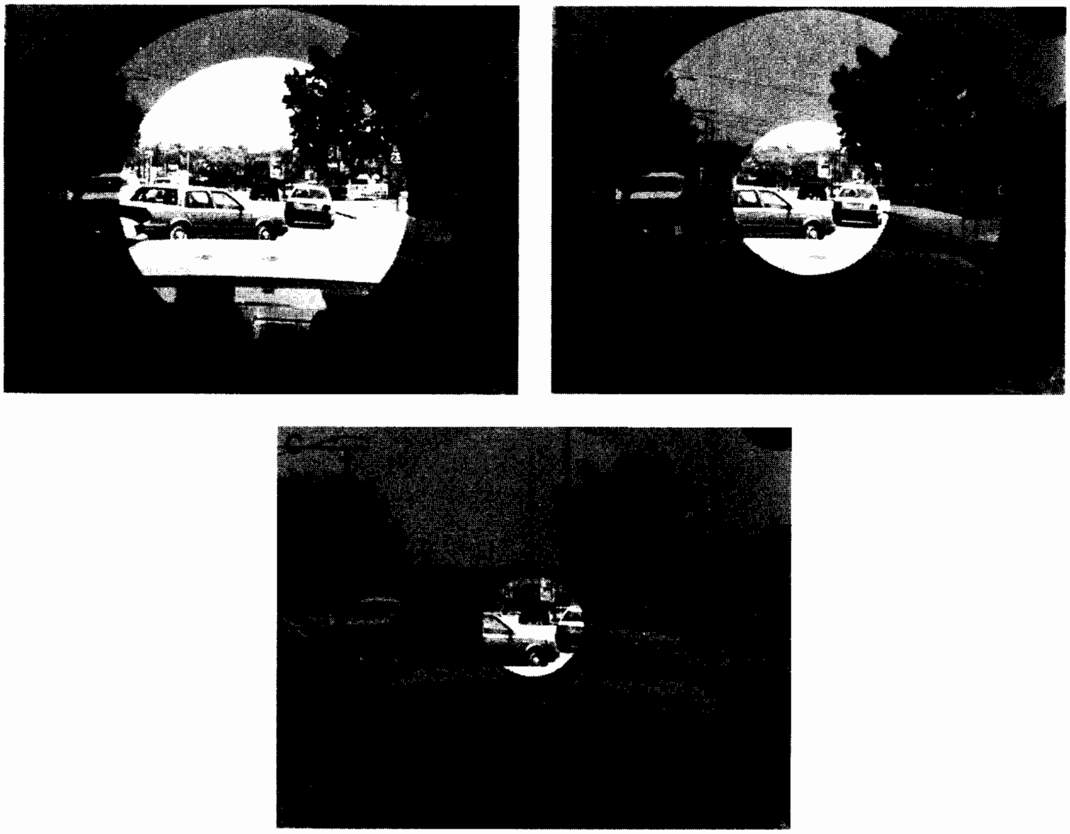

Fig. 1. Impact of increasing UFOV® restriction. (*A*) Twenty percent reduction in UFOV®. (*B*) Fifty percent reduction in UFOV®. (*C*) Ninety percent reduction in UFOV®.

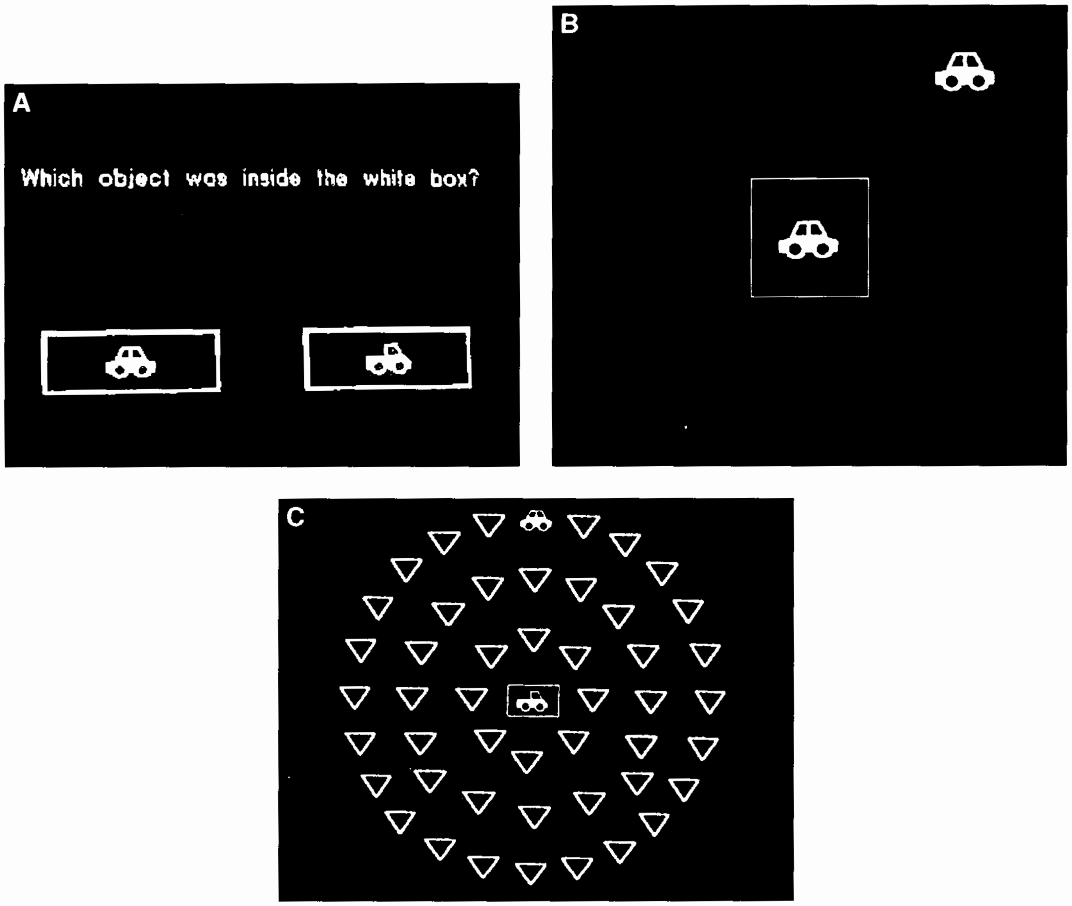

Fig. 2. UFOV® test stimuli. (*A*) UFOV® subtest 1: processing speed. (*B*) UFOV® subtest 2: divided attention. (*C*) UFOV® subtest 3: selective attention.

further eccentricities than less conspicuous targets given a constant duration, and targets presented for longer stimulus durations are recognized at further eccentricities given a constant conspicuity. Thus, useful field of view size can be manipulated by varying stimulus duration, conspicuity, and central task difficulty, and these variables interact with age and stimulus eccentricity in a variety of ways. Limits of the useful field of view are affected by many factors, such as the presence of a secondary task and of background distractor stimuli and the similarity between target and distractor stimuli [55–61]. The impact of these variables is greater for older adults because aging is associated with a restricted field of view [53,58,62,63].

The influence of age on the useful field of view has been evaluated in a number of ways. Ball et al [64] evaluated three mechanisms for possible age-related changes in performance on the UFOV® test: (1) reduced speed of visual processing in older adults, (2) reduced ability to divide attention, and (3) greater susceptibility to distractors. Each of these abilities has previously been related to age and driving performance using standard neuropsychological tests. Using an individual-differences approach to evaluate performance across the range of obtained scores, they noted that though age alone accounted for approximately half the variance in UFOV® test scores, individual abilities in the areas of visual processing speed, dividing attention, and susceptibility to distractors accounted for 91% of the variance in scores. In other words, once information on these three attributes is known, age becomes superfluous information. Thus, the general age trends observed on the UFOV® test result from a higher prevalence of age-related decrements in visual information processing abilities among older adults rather than a generalized age-related decline. Comparing average performance across age groups obscures the unique reasons for performance limitations in different persons.

Paradoxically, visual sensory field loss is not a necessary condition for a constricted useful field of view. Many older adults who have impairments in the useful field of view have normal visual fields. Thus, useful field of view depends on the integrity of visual sensory information, but it also depends on attentional mechanisms, as described earlier [65]. In this sense, it is a more comprehensive measure of visual information processing ability than visual sensory status alone.

The past 10 to 20 years have been marked by technological advances in evaluation and in intervention approaches aimed at enhancing the useful field of view. For example, speed-of-processing training, which targets the speed with which complex visual information is processed, is one method by which the useful field of view can be enhanced [31,66]. In large part, these advances have been fueled by studies demonstrating the strong relation between the useful field of view and driving. For example, Wood and Troutbeck [67] found a significant correlation between the useful field of view and driving performance on a closed course. In addition, useful field of view has been related to performance on a driving simulator [68,69]. Finally, there is a strong relation between the useful field of view and both crash history and prospective state-recorded crashes [45,70]. Thus, there is converging evidence from multiple investigations that visual search skills are strongly related to driving performance among older adults. Historically, few measures have adequately captured the individual characteristics underlying differences in driving performance. Recently, however, technological advances have occurred in the assessment of vision, higher-order information processing, cognition, and driving behaviors through increasingly refined and computer-based measurement tools and simulator-based technology. These advances have contributed to our knowledge of what should and what should not be measured in the quest to identify and intervene on behalf of at-risk drivers. In particular, the UFOV® test appears to capture higher-order visual processes that not only correlate moderately with performance on a variety of cognitive tests but also provide unique information about driving risk.

Summary

Visual function declines with age in a variety of ways. It must also be kept in mind, however, that the results reported here are primarily group findings. When evaluating the performance of older persons, there is extremely wide variability, and even though average performance may decline as a function of age, many older adults maintain excellent visual function throughout their lifetimes. It is important to keep the variability of individual performance in mind to avoid ageist stereotypes.

Although declines in age-related vision are well documented, it is less clear why these declines have occurred. Most recent studies have controlled for criterion differences by using forced-choice methods. These studies confirm that even after correcting for differences in threshold criteria, age-related declines persist. Many other studies have controlled for optical changes using a variety of techniques. Again, some age-related declines still exist. Although it is widely believed that the neuroanatomy and physiology of the visual pathways are affected by aging, there is still relatively little understanding of how these changes impact visual function. Thus, there is a need for further studies to link potential neural mechanisms to observed changes in functional visual performance. Furthermore, there is also a possibility that there may be multiple sites of decline within a given person and that these sites of decline may vary across persons. Thus, the use of an individual-differences approach is needed to evaluate the many potential explanations for sensory decline.

Finally, there is frequently a discrepancy between performance in the laboratory and real-world performance. In trying to predict the performance of real-world tasks and in designing the best environments for the elderly, sensory function should not be considered in isolation. Rather contributing factors such as cognitive ability, expectations, distractions, and other health-related and motor problems must also be considered. Traditional clinical measures of visual function, though appropriate for evaluating the presence of disease, are often inadequate in explaining everyday performance impairments. Thus, further research is needed to fully understand the complex interactions between sensory, cognitive, motor, economic, and physical factors that together determine one's level of ability or disability in everyday tasks.

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