



# Aging does not affect integration times for the perception of depth from motion parallax



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## ABSTRACT

To successfully navigate throughout the world, observers must rapidly recover depth information. One depth cue that is especially important for a moving observer is motion parallax. To perceive unambiguous depth from motion parallax, the visual system must integrate information from two different proximal signals, retinal image motion and a pursuit eye movement. Previous research has shown that aging affects both of these necessary components for motion parallax depth perception, but no research has yet investigated how aging affects the mechanism for integrating motion and pursuit information to recover depth from motion parallax. The goal of the current experiment was to assess the integration time required by older adults to process depth information. In four psychophysical conditions, younger and older observers made motion and depth judgments about stationary or translating random-dot stimuli. Stimulus presentations in all four psychophysical conditions were followed by a high-contrast pattern mask, and minimum stimulus presentation durations (stimulus-to-mask onset asynchrony, or SOA) were measured. These SOAs reflect the minimum neural processing time required to make motion and motion parallax depth judgments. Pursuit latency was also measured. The results revealed that, after accounting for age-related delays in motion processing and pursuit onset, older and younger adults required similar temporal intervals to combine retinal image motion with an internal pursuit signal for the perception of depth. These results suggest that the mechanism for motion and pursuit integration is not affected by age.

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## 1. Introduction

Older adults have deficits in many visuospatial domains, including motion and depth information processing (Andersen, 2012; Owsley, 2011). Many of these age-related deficits are linked to mobility problems, such as balance issues and falls, and accidents while operating motor vehicles (Choy, Brauer, & Nitz, 2008; Owsley et al., 1998); as such, a full understanding of how visuospatial functioning is affected by age is important for both preventing and alleviating negative outcomes. One visuospatial process that is integral to successfully navigating throughout the world is the recovery of depth from motion parallax.

Motion parallax (MP) is produced through the translation of an observer or scene. During translation, the moving observer maintains fixation on objects within the scene, generating smooth pursuit eye movements (Miles & Busettini, 1992), while stationary objects within the scene appear to move relative to one another, creating relative image motion on the retina. The visual system integrates the motion and pursuit information to generate a depth

percept (Nawrot & Joyce, 2006). The Motion/Pursuit Ratio (M/PR) describes the geometric relationship of the velocity of objects moving on the retina ( $d\theta$ ), pursuit eye movement velocity ( $d\alpha$ ), viewing distance to the point of fixation ( $f$ ), and object distance from fixation ( $d$ ) (Nawrot & Stroyan, 2009; Stroyan & Nawrot, 2011):

$$\frac{d}{f} \approx \frac{d\theta}{d\alpha} \quad (1)$$

The role of the pursuit eye movement signal is to disambiguate the depth sign in the perception of depth from MP. The relationship of retinal image motion and pursuit eye movement direction is an orderly one: objects with retinal motion in the same direction as pursuit are perceived as being nearer in depth than objects with retinal image motion in the opposite direction (Nawrot & Joyce, 2006). Indeed, an intact pursuit signal is so necessary for disambiguating depth from MP, that experimentally controlling pursuit eye movements—that is, effectively nulling the eye movement that is usually necessary for maintaining fixation on a translating stimulus—results in an ambiguous depth percept (Naji & Freeman, 2004; Nawrot & Joyce, 2006). Neuro-physiological studies have likewise shown that the pursuit eye movement signal is necessary for disambiguating depth from MP. Neurons in area MT of the

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macaque monkey are responsive to depth from motion parallax, and even show depth-sign selectivity (Nadler, Angelaki, & DeAngelis, 2008; Nadler, Nawrot, Angelaki, & DeAngelis, 2009). Interestingly, the responses of these depth selective neurons were tied to the direction of pursuit eye movements, and *not* to the direction of head movements.

The geometry of depth from MP is, by nature, dynamic. That is, as one moves through the environment, or as objects in the environment move, the parameters of the M/PR ( $d\theta$ ,  $d\alpha$ , and  $f$ ) change in relation to one another and to the observer. Thus, recovering relative depth information quickly is important for successful navigation throughout the world. Using a masking paradigm, Nawrot and Stroyan (2012) found that younger observers require only 65–75 ms to integrate motion and pursuit signals to recover depth from MP. This rapid recovery of MP depth information is contrary to the results of prior research, which showed that depth from motion is slow and must “build up” (see, e.g., Andersen & Bradley, 1998). A natural (and important) extension of this finding is to investigate the temporal parameters of depth from MP in older adults. Recent research has shown that age independently affects the motion and pursuit signals for depth from MP (Holmin & Nawrot, 2016). Motion thresholds increase and pursuit accuracy decreases with increasing age, resulting in different motion and pursuit signals in younger and older adults.

Other research has examined the effects of age on the temporal parameters for integrating motion information and for initiating pursuit eye movements—that is, generating or acquiring the component signals for depth from MP. The few published studies of aging and temporal integration of motion information have produced conflicting results. Roudaia, Bennett, Sekuler, and Pitz (2010) presented younger and older observers with a random-dot two-frame apparent motion sequence in which the magnitude of dot displacement and the duration of the interstimulus interval (ISI) varied. Observers were required to discriminate the direction of dot displacement. At higher ISIs (60–160 ms), older observers performed worse (i.e., made fewer correct direction judgments) than younger adults across all displacement levels. That is, the maximum temporal interval at which two frames could be integrated in order to make a directional judgment was reduced in older observers. The results of Roudaia et al. indicate, then, that older adults have deficits in temporal integration of motion information.

In contrast to Roudaia et al. (2010), in a study of shape identification, Andersen and Ni (2008) found no effect of age on temporal integration. In their first study, older and younger adults identified two-dimensional (2-D) shapes defined by spatial and temporal properties. An opaque shape, such as a triangle, was drawn on a random-dot background. The shape had no boundaries, but translated across the background, occluding background dots as it translated. This “accretion and deletion” of the background texture information allowed the boundary of the shape to be identified. When the dot density was decreased, older observers' shape identification performance was worse than younger adults', indicating that spatial integration was impaired in older adults. By manipulating the velocity at which the shape translated, the amount of information that was available to observers was increased or decreased: increasing velocity increased the rate of accretion/deletion of background elements, thereby providing more temporal information. Both younger and older adults' performance increased as velocity increased, and the rate of increase across velocity was constant for younger and older adults, suggesting that age does not affect temporal integration. In a second study, spatial information (density) and velocity (8 deg/s translation) were held constant, while the individual dots that made up the background were varied by point lifetimes (i.e., duration of the individual dots). Again, there was no effect of age on performance—older and younger

adults performed equivalently across different point lifetimes. Similarly, Arena, Hutchinson, and Shimozaki (2012) found that there was no effect of age on global motion thresholds when the dots comprising the stimulus were varied in speed, indicating that age did not affect temporal integration.

While the results of these studies appear at first to be contradictory, there are several conceptual differences that must be taken into consideration. Roudaia et al.'s task essentially assessed observers' abilities to integrate motion information over two frames (i.e., displacement thresholds), while Andersen and Ni's and Arena et al.'s studies assessed performance for continuously-moving stimuli that varied in velocity or point lifetimes. It is therefore likely that these studies measure different aspects of temporal integration (velocity vs. point lifetimes vs. displacement) in older adults. Another important difference in these studies is that in Roudaia et al.'s study, the longest stimulus duration was 440 ms, while the stimulus duration in Arena et al.'s study was 853 ms, and was 5 s in Andersen and Ni's. It is possible that older adults' temporal processing of motion information is slowed, but that this age effect will not be apparent given a stimulus of prolonged duration, hence the conflicting results across these three studies.

It is not only motion processing ( $d\theta$ ) that is affected by age. Studies of the effects of age on pursuit eye movements have revealed that older adults require longer temporal intervals to initiate a pursuit eye movement. Older adults typically have pursuit latencies approximately 35–50 ms longer than younger adults', for pursuit stimuli translating at velocities between 5 and 20 deg/s (Knox, Davidson, & Anderson, 2005; Sharpe & Sylvester, 1978). Handke and Büttner (1999) also found a significant age difference in pursuit onset for a target translating at 10 deg/s; however, older adults had only 10 ms longer latencies compared to younger adults.

In summary, evidence suggests that older adults are delayed in processing motion and pursuit information, and, by extension, take longer to generate or acquire the component  $d\theta$  and  $d\alpha$  signals necessary for depth from MP. In addition to generating these component signals, the visual system must also integrate the two signals in order to produce the perception of depth from MP. Younger adults require approximately 20–35 ms to recover motion information, and 65–75 ms to recover depth information (Nawrot & Stroyan, 2012). The additional 40–45 ms necessary for younger adults to complete MP depth processing (that is, the processing interval beyond the 20–35 ms motion processing time) likely reflects the processing time necessary for acquiring and integrating the pursuit ( $d\alpha$ ) signal with the motion ( $d\theta$ ) signal to generate a perception of depth from MP. The goal of the current experiment was to assess the time required by older adults to integrate motion and pursuit to generate a depth percept. Considering older adults' delayed processing for motion and pursuit information, it is possible that the temporal parameters of the motion/pursuit integration mechanism will likewise be delayed, reflecting generalized slowing of visuospatial processing (Salthouse, 1996). Alternatively, aging may have no effect on the temporal parameters of the integration mechanism, and any slowing in MP depth processing will reflect slowing in the motion and pursuit processes independently.

In the current experiment, observers made judgments about motion direction or about depth phase across four different conditions. To assess processing delays, we employed a backward masking paradigm to measure threshold stimulus durations necessary for younger and older observers to make motion and depth judgments. In masking paradigms, in order to make a stimulus judgment, all processing must occur before the appearance of the mask, which interrupts stimulus processing (Breitmeyer, 1980; Enns & Di Lollo, 2000). In no-mask conditions, stimulus processing may continue after the stimulus has been removed, so that observers may require only very brief stimulus presentations in order to

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