Neuropsychology
2002, Vol. 16, No. 2, 140–145

DOI: 10.1037//0894-4105.16.2.140

Priming of Two-Dimensional Visual Motion Is Reduced in Older Adults

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Previously, Y. Jiang, P. Greenwood, and R. Parasuraman (1999) reported that priming of rotating three-dimensional visual objects is age sensitive. The current study investigated whether there is also an age-related difference in priming with simple two-dimensional (2-D) moving stimuli (i.e., whether a prime stimulus moving in a particular direction causes a subsequent ambiguous target stimulus to be seen moving in the same direction as the prime). In 2 experiments, younger and older adults judged the directions of moving sine-wave gratings. Groups differed neither in determining the direction of a single 2-D movement nor in detecting motion reversals in successively moving gratings. However, the older group showed a significant reduction in the extent of 2-D motion priming. The decrement in older adults for visual motion priming may reflect age-related changes in temporal processing in human visual cortex.

Perception of a visual event can be biased, or *primed*, by prior exposure to the same or related visual information. For instance, in the case of repetition priming, people are generally faster to name an object they have seen previously than a new object, even though they may not consciously remember having seen the object before (Schacter & Buckner, 1998). Visual motion perception can also be biased by previous exposure to a motion signal (Anstis & Ramachandran, 1987; Blake, 1998; Jiang, Pantle, & Mark, 1998; Pantle, Gallogly, & Piehler, 2000; Pinkus & Pantle, 1997; Raymond & Isaak, 1998). This and other varieties of perceptual priming represent a type of automatic learning (or implicit memory) that differs from conscious recollection.

Perceptual priming has been found to decline in magnitude in older adults (Cherry & St. Pierre, 1998; Fleischman & Gabrieli, 1998; Howard & Wiggs, 1993; Small, Hultsch, & Masson, 1995). Although many different paradigms have been used, to date most studies examining aging and perceptual priming have used static rather than moving visual stimuli (Fleischman & Gabrieli, 1998). Thus, comparatively little is known of age-related changes in priming with moving stimuli, which constitute the bulk of everyday visual experience. Processing of motion information is essential for visually guided action in both younger and older adults. A complete understanding of priming phenomena therefore requires an analysis of priming effects with moving stimuli.

Visual motion priming is typically examined by testing how a moving stimulus can disambiguate the direction of movement of a subsequent ambiguously moving stimulus or can otherwise bias perception of its motion. The priming effect is generally short-lived, disappearing after a few seconds (e.g., Anstis & Ramachandran, 1987; Pinkus & Pantle, 1997; Raymond, O'Donnell, & Tipper, 1998). Priming also points to attentional modulation of human motion sensitivity. Unlike the waterfall illusion or the motion aftereffect (see Pantle, 1998, for a review), motion priming occurs when the motion of a subsequent stimulus (target) is perceived to be the same as that of a previous stimulus (prime). For example, seeing a three-dimensional (3-D) object rotating clockwise in depth influences the subsequent perception of an ambiguously moving 3-D object, which is then also reported to be moving clockwise (Jiang, et al., 1998). Various control experiments have been conducted to rule out the possibility that the same-direction judgments are not due to a simple response bias but instead reflect perceptual priming.

Jiang, Greenwood, and Parasuraman (1999) previously reported that this 3-D priming effect is markedly reduced in older adults compared with younger adults. That study was

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Portions of this article were presented at the Cognitive Aging Conference in April 2000, Atlanta, Georgia. This work was supported by National Institutes of Health Grants AG07569 to Raja Parasuraman and AG00986 to Yang Jiang and by Natural Science Foundation (China) Grant 30070262 and Chinese Academy of Science Grant KJCX1-07 to Yue-Jia Luo.

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the first to report that motion priming is age sensitive. Because motion priming can take many forms, the generality of the effect remains an open question. Motion information is processed in several hierarchical stages in the visual cortex, with processing of circular motion and rotation in 3-D occurring at a relatively high level in the hierarchy (R. A. Andersen, 1997; Bex, Metha, & Makous, 1998; Felleman & Van Essen, 1991; Tanaka, 1998). Compared with 3-D motion priming, two-dimensional (2-D) motion priming involves the processing of 2-D motion translation, which precedes the processing of 3-D rotation in depth. Is visual priming of 2-D motion therefore also age sensitive like 3-D motion priming? This question is of interest in order to determine the earliest stage of visual priming that is age sensitive.

We used a 2-D motion priming paradigm adapted from Pinkus and Pantle (1997). In this task, participants view two successively presented sine-wave luminance gratings: (a) a prime stimulus that moves unambiguously in one direction, as induced by a 90° phase shift in the sine-wave grating, which was followed by (b) a target stimulus whose direction of movement is ambiguous, implemented with a 180° phase shift in the sine-wave grating, which results in movement being perceived in either the left or the right direction. When this ambiguously moving stimulus (target) is preceded by the directionally unambiguous moving stimulus (prime), the ambiguous stimulus appears to move in the same direction as the unambiguous stimulus. In other words, the prime motion serves to disambiguate the ambiguous motion of the target stimulus. In two experiments, we examined 2-D motion priming using this task in younger and older adults.

Experiment 1: Perception of Single Motion Jumps in Younger and Older Participants

The aim of the first experiment was to investigate whether younger and older observers would perceive a simple motion jump differently under above-threshold conditions. Because older adults have lower contrast sensitivity than younger adults (Kline & Scialfa, 1996; Scialfa, Grarvey, Tyrrell, & Leibowitz, 1992), older adults perform more poorly than younger adults in detecting motion or motion-defined surfaces and in discriminating the direction of motion at near-threshold conditions or when contrast is poor (G. J. Andersen & Atchley, 1995; Gilmore, Wenk, Naylor, & Stuve, 1992; Owsley, Sekuler, & Siemsen, 1983; Trick & Silverman, 1991; Warren, Blackwell, & Morris, 1989). To eliminate the possible confounding of an age-related difference in priming with an age difference in motion perception sensitivity, we tested the motion direction judgments of single motion jumps using high-contrast stimuli that were well above threshold.

Method

Participants. Twenty younger adults ($M_{age} = 22$) and 20 older adults ($M_{age} = 68$) participated. The younger participants were college students from the Catholic University of America. The older participants were community-living adults with an equivalent number of years of education and who did not have signs of cognitive impairment as assessed by the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975). All participants had corrected vision of at least 20/40 in Snellen and Rosenbaum eye examination tests.

Visual stimuli and displays. The apparent motion stimuli used in the two experiments were image sequences of vertical sine-wave gratings, constructed using the same methods as in the 2-D motion priming experiments reported by Pinkus and Pantle (1997). In Experiment 1, we used three types of single-step motion jump sequences. Thus, priming was not examined; rather, we used single stimuli to examine the baseline motion perception of younger and older adults. Double-step motion stimuli were used to examine priming in Experiment 2. A 90° or a −90° phase shift in a sine-wave grating is associated with perception of an unambiguous single motion step to the right or to the left, respectively. A 0°–180° counterphase shift between frames results in perception of movement to either the left or the right (ambiguous or bistable motion), even though the physical stimuli remain the same (see Figure 1a). Thus, the three types of single movements were (a) unambiguous left, (b) unambiguous right, and (c) ambiguous left or right.

The motion jumps were viewed through a circular hole in a cardboard sheet that was 16 cm in diameter, at a viewing distance of 104 cm (8.8° of visual angle). The average luminance of the display was 14 cd/m^2.

Procedure. Participants were instructed to look globally toward the center of the computer screen on which single and double motion sequences were shown. After viewing each motion jump, the observer reported the direction of the motion (right or left) by depressing one of two response keys. Participants were told to

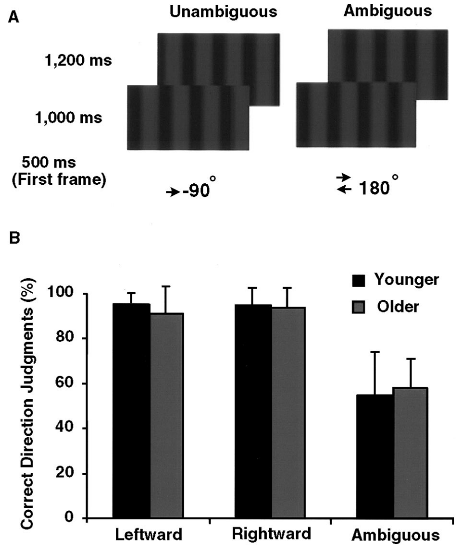

Figure 1. Examples of the single motion step stimuli used in Experiment 1 and the corresponding proportions of motion direction judgments reported. A: Unambiguous motion to the left or the right was implemented with a −90° or 90° phase shift between frames, whereas a 180° counterphase shift was perceived as ambiguous motion. B: Mean proportions of correct motion direction judgments in the younger and older groups. Percentage correct is defined by the perceived direction judgment that matched the physical direction of movement.

press both keys if they were not sure or if they had missed seeing the stimuli because they had blinked their eyes. A total of 70 trials for each of the three conditions in Experiment 1 were administered.

Results

Perceptual judgments. The proportions of correct perceptual judgments of the direction (left or right) of the unambiguous single motion steps were computed for each observer. There was no main effect of age. The younger and older groups did not differ significantly in the mean proportion of correct judgments, $F(1, 38) = 2.71$, $p > .10$. The single leftward motion step was perceived correctly 96.4% ($SE = 0.83\%$) and 91.3% ($SE = 2.20\%$) of the time by the younger and older observers, respectively. The corresponding values for the single rightward motion trials were 95.5% ($SE = 1.28\%$) and 93.6% ($SE = 1.97\%$) for the younger and older groups, respectively. For the perceptually ambiguous motion (180° phase shift) trials, perceptual judgments by younger and older participants were also comparable and at chance, at 58.6% ($SE = 2.83\%$) and 55.7% ($SE = 2.40\%$) for younger and older groups, respectively (see Figure 1b). Thus, younger and older observers were equally accurate at perceiving either leftward or rightward single unambiguous motion steps (over 90%) and equally guessed at chance (around 50%) when motion was ambiguous.

Reaction time (RT). We also measured the RT for perceptual judgments in both groups. Even though the younger observers tended to respond somewhat faster than the older observers, there was no main effect of age (i.e., there was no significant difference between the two age groups, $p > .10$). Mean RTs for the unambiguous motion steps (left or right) were 517 ms ($SE = 23$ ms) and 562 ms ($SE = 26$ ms) for the younger and older groups, respectively. RTs for the ambiguous motion trials were 581 ms ($SE = 28.7$ ms) and 654 ms ($SE = 27.5$ ms) for the younger and older groups, respectively. Post hoc comparisons between the younger and the older groups at each of the three conditions were not significant ($p > .05$, corrected for multiple comparison).

Experiment 2: Perception of Motion Priming and Motion Reversal in Younger and Older Participants

Both younger and older observers judged two successive motion jumps in the present experiment. In the motion priming condition, an unambiguous jump (left or right) was followed by an ambiguous jump. If priming occurred, observers would report both jumps to be in the same direction (both left or both right). A motion reversal condition was used as a control condition. In this condition, two unambiguous jumps were presented in succession but in opposite directions (e.g., left–right or right–left). We included the motion reversal condition to test whether younger and older observers would be equally sensitive to motion reversals. If so, any differences in motion priming between younger and older participants could not be attributed to a bias on the part of one group for perceiving two motions in the same direction.

Method

Participants. The same groups of participants as in Experiment 1 were tested.

Visual displays and task. Two motion steps were used to examine priming effects in Experiment 2. The corresponding perception was two moving steps. The first motion step was always an unambiguous motion step (to either the left or the right) as used in Experiment 1. The second motion step was either an ambiguous motion in the case of the motion priming condition or an unambiguous motion in the motion reversal condition. In the motion priming condition, the direction of movement of the second stimulus was ambiguous (either left or right). In the motion reversal condition, the second stimulus moved unambiguously in one direction but always in the opposite direction to that of the first stimulus (e.g., to the left if the first stimulus had moved to the right and to the right if the first stimulus had moved to the left). The phase shifts between successive sine-wave gratings in the motion reversal trials were in the sequence $0° \rightarrow 90° \rightarrow 0°$, which was perceived consistently as two opposite motion directions (right then left or left then right). This is because, as indicated before, 90° phase shifts, whether negative ($0° \rightarrow -90° \rightarrow 0°$) or positive ($0° \rightarrow 90° \rightarrow 0°$) are unambiguous. The phase shifts between successive frames in the priming condition were in the sequence of $0° \rightarrow 90° \rightarrow 270°$ or $0° \rightarrow -90° \rightarrow -270°$. This resulted in an unambiguous movement to the right or the left (90° shift), followed by ambiguous movement (180° shift). There were three time delays (200, 400, and 1,000 ms) between the first and the second motion steps.

Each participant (younger or older) judged 80 trials of motion directions for each of the six conditions (motion priming and reversals at three time delays). Within each condition, the first unambiguous motions were balanced between leftward and rightward directions. Even though participants were unable to determine on any given trial which motion condition was being run, the conditions were presented in random order to minimize observer response bias.

Results

Perceptual judgments. In the motion priming condition, the degree of motion priming was indexed by the proportion of trials on which the second motion direction was judged to be the same as the first (e.g., left–left). Figure 2 shows the percentage of reports of seeing two motion steps in the same direction as a function of the time delay between the two motion jumps in both younger and older groups. If there was no priming, then the proportion of times both motion jumps were reported to be in the same direction should be 50%. By this criterion, both groups exhibited a motion priming effect at time delays of 200 and 400 ms. Figure 2 indicates that although the older group showed a lower percentage priming effect, 2-D motion priming decreased over time at a similar rate for the two groups. In the motion reversal conditions, both younger and older participants were equally accurate in detecting that the two successive motions were in the opposite direction.

A 2 (age groups) × 2 (priming vs. reversals tasks) × 3 (time delays) repeated-measures analysis of variance (ANOVA) revealed a significant main effect with a between-groups factor of age (younger vs. older), $F(1, 38) = 8.23$, $p < .01$. The main effect of tasks (motion priming vs. reversals) was significant, $F(1, 38) = 214.67$,

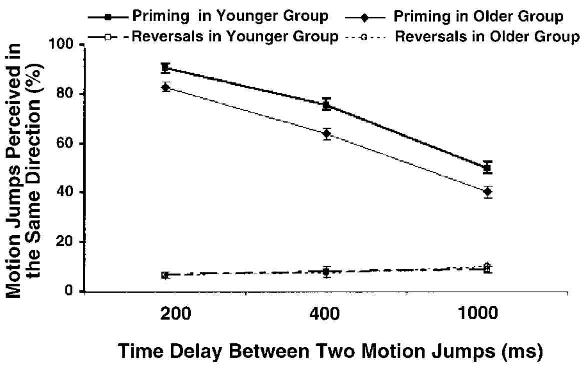

Figure 2. Perceiving motion priming and motion reversals. The proportion of same-direction judgments of two successive motion steps as a function of the time delay between the two motion steps. The higher the percentage, the higher amount of priming tendency. Fifty percent is the chance level. The proportion of same-direction judgments in the motion reversal trials is also shown. Error bars indicate standard errors of the mean.

$p < .01$. The Age × Tasks interaction was also significant, $F(1, 38) = 214.67$, $p < .01$. In other words, the age difference in judgments was primarily due to differences in the motion priming condition rather than in the motion reversal condition. Additionally, the main effect of time delays between prime and targets (200, 400, and 1,000 ms) was also significant, $F(2, 38) = 116.85$, $p < .01$. The Age × Time Delay interaction was not significant ($p > .10$). We used the Bonferroni correction for all *F* tests involving the repeated-measure factors. Post hoc comparisons revealed that the degree of priming differed significantly between the two age groups at each of the three time delays of 200, 400, and 1,000 ms ($p < .01$). In contrast, the younger and the older groups were equally sensitive to motion reversals at each of these time delays ($p > .60$).

RT. The 2 (age groups) × 2 (tasks) × 3 (time delays) ANOVA showed main effects of age, $F(1, 38) = 4.85$, $p < .05$, and tasks, $F(1, 38) = 18.32$, $p < .01$, but no main effects of time delay ($p > .10$). There was a strong interaction between task and time delay, $F(1, 38) = 7.18$, $p < .01$. Furthermore, the interaction between task and age was significant, $F(1, 38) = 5.32$, $p < .05$. In contrast to the perceptual judgment data, there was an interaction of time delay and age, $F(2, 76) = 4.87$, $p < .01$. Post hoc tests revealed that the RTs for judging double motion directions by younger and older adults differed significantly only in the priming condition with short time delays. At the 200 ms delay, RTs were 667 ms ($SE = 25$ ms) and 806 ms ($SE = 31$ ms) for the younger and older groups, respectively ($p < .005$). At the 400 ms delay, RTs were 695 ms ($SE = 23$ ms) and 834 ms ($SE = 39$ ms) for the younger and older groups, respectively ($p < .05$). The two groups did not differ significantly at the 1,000-ms delay ($p > .10$), when the priming effect was reduced to the chance (50%) level. In the motion reversal conditions, RTs for the younger group were somewhat faster than for the older group, but the difference was not significant ($p > .05$) at the 200-ms (683 vs. 758 ms), 400-ms (694 vs. 727 ms), or 1,000-ms (704 vs. 735 ms) delays. Thus, these data indicate that the older observers were as fast as the younger observers in identifying directional reversals in two successive motion steps. However, the older observers were slower in resolving motion ambiguity in the priming condition.

Discussion

When a stimulus that moves ambiguously in one of two directions in two dimensions (e.g., left or right) is preceded by directionally unambiguous movement, the ambiguous stimulus is perceived to move in the same direction as the unambiguous stimulus. The present results indicate that this so-called motion priming effect, which decayed over a period of about 1 s, was exhibited by both younger and older adults. However, the degree of motion priming was significantly reduced in older adults compared with younger adults.

The control conditions we used rule out explanations for the pattern of results on the basis of age-related loss in motion sensitivity, increased response bias, or generalized cognitive slowing. First, it is well known that there are age-related differences in contrast sensitivity and basic aspects of motion perception, such as threshold detection of motion, identification of shape from motion, or detection of the direction of motion (G. J. Andersen & Atchley, 1995; Gilmore et al., 1992; Scialfa et al., 1992; Trick & Silverman, 1991; Warren et al., 1989). However, many of these differences are observed only when older adults are shown either low contrast visual stimuli or when the discriminations involve small differences (e.g., Gilmore, Morrison, Behi, & Manjeshwar, 2000). Because we used high-contrast stimuli that were easily visible to both younger and older observers and large differences in the stimuli to be discriminated (i.e., left or right direction), our results cannot be accounted for simply in terms of reduced visual sensitivity in older adults. Moreover, the results of Experiment 1, in which baseline motion direction judgments were assessed, confirmed that the older group was highly accurate and equivalent to the younger group in making such judgments.

Increased response bias in the older group, that is, the greater tendency to report any two successive motion directions as the same, can also be ruled out by the results of the motion reversal condition in Experiment 2. Older adults were as accurate as younger adults in detecting motion reversals and in responding appropriately (e.g., left–right or right–left). Older adults did not simply report on all trials that they perceived the two motion sequences as always being in the same direction, and given that observers could not easily predict the type of condition on any given trial, priming or reversal, there would be little benefit to the older observers of following such a reporting strategy.

Third, the results seem unlikely to be secondary to general age-related cognitive slowing. The older group had significantly longer RTs than the younger group in the motion priming condition. This could be interpreted as slowing related to increased difficulty in resolving ambiguous 2-D motion. However, any such slowing was selective rather than general. There were no significant age differences in RTs either in the single motion condition of Experiment 1 or in the motion reversal condition of Experiment 2.

The ruling out of these alternate explanations suggests that the results are indicative of an age-related difference in the priming of 2-D motion. In a previous study, Jiang et al. (1999) showed that motion priming with 3-D moving objects decreases with age. Thus, 3-D motion priming as well as 2-D motion priming, which is postulated to involve an earlier stage in the visual processing hierarchy (R. A. Andersen, 1997; Bex et al., 1998), are both age sensitive. Taken together, the results add to the growing evidence that several forms of perceptual priming show age-related reduction (Cherry & St. Pierre, 1998; Small et al., 1995).

The neural mechanisms underlying age-related reduction in motion priming are currently the focus of investigations using both psychophysical and neuroscience methods (Luo, Jiang, Lawsin, & Parasuraman, 2000a, 2000b). The cortical areas that mediate motion priming form part of the dorsal visual pathway (Goodale & Milner, 1992; Ungerleider & Mishkin, 1982). Single-cell recording and lesion studies have established that the monkey middle temporal (MT) visual cortex or visual area 5 (V5) is critically involved in motion-related visual processing (e.g., Allman, Miezin, & McGuinness, 1985; Newsome, Britten, & Movshon, 1989). Cells in the MT visual cortex are selective for simple motion direction and speed (Maunsell & Van Essen, 1983). Recent functional brain imaging studies in humans have shown that simple directionally moving stimuli, such as the moving sine-wave gratings used in the present study, activate human MT/V5 and other visual cortical areas, consistent with the motion-related cortical areas identified in primates (e.g., McCarthy et al., 1995; Tootell et al., 1995; Watson et al., 1993).

Unlike other types of perceptual priming, the 2-D and 3-D motion priming effects that we have examined persist for only 1–2 s. (In contrast, most repetition priming studies for static 2-D objects have examined effects over relatively long time intervals, from minutes to days; see Cave, 1997.) Thus, the motion priming effect is beyond the temporal resolution of functional magnetic resonance imaging, which currently provides the best spatial resolution for the localization of neural activity in the human brain. Luo et al. (2000b) therefore used event-related potentials (ERPs) to examine the neural correlates of 2-D motion priming in younger and older adults. Luo et al. found a temporal delay of about 200 ms in the neural activity related to the perception of target motion direction in the older group, as reflected in the peak latencies of both early and late ERP components recorded from posterior sites. A delay in the neural response to the second target motion in a prime target paradigm will result in a weaker impact of the neural response generated by the motion prime. If motion priming reflects the temporal summation of motion-processing signals in the visual cortex, then any such delay may lead to reduced priming. The decrement in motion priming in older adults may therefore reflect age-related changes in temporal processing of motion signals in the visual cortex.

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Received February 22, 2001
Revision received August 13, 2001
Accepted August 13, 2001 ■