Healthy older observers cannot use biological-motion point-light information efficiently within 4 m of themselves

Isabelle Legault
Visual Psychophysics and Perception Laboratory, 3744 Jean-Brillant, School of Optometry, Université de Montréal, Montreal, Quebec H3T 1P1, Canada; e-mail: isabelle.legault.3@umontreal.ca

Nikolaus F Troje
Department of Psychology, Department of Biology, School of Computing, Queen’s University, Kingston, Ontario K7L 3N6, Canada; e-mail: troje@queensu.ca

Jocelyn Faubert
Visual Psychophysics and Perception Laboratory, 3744 Jean-Brillant, School of Optometry, Université de Montréal, Montreal, Quebec H3T 1P1, Canada; e-mail: jocelyn.faubert@umontreal.ca

Received 15 September 2011, in revised form 6 January 2011; published online 21 February 2012

Abstract. Healthy aging is associated with a number of perceptual changes, but measures of biological-motion perception have yielded conflicting results. Biological motion provides information about a walker, from gender and identity to speed, direction, and distance. In our natural environment, as someone approaches us (closer distances), the walker spans larger areas of our field of view, the extent of which can be underutilized with age. Yet, the effect of age on biological-motion perception in such real-world scenarios remains unknown. We assessed the effect of age on discriminating walking direction in upright and inverted biological-motion patterns, positioned at various distances in virtual space. Findings indicate that discrimination is worse at closer distances, an effect exacerbated by age. Older adults’ performance decreases at distances as far away as 4 m, whereas younger adults maintain their performance as close as 1 m (worse at 0.5 m). This suggests that older observers are limited in their capacity to integrate information over larger areas of the visual field and supports the notion that age-related effects are more apparent when larger neural networks are required to process simultaneous information. This has further implications for social contexts where information from biological motion is critical.

Keywords: Biological motion, aging, collision avoidance, complexity.

1 Introduction

Normal aging is accompanied by various age-related declines, including sensitivity to motion. For example, older adults exhibit deficits in perceiving translational motion (Billino et al 2008) and coherent motion (Gilmore et al 1992; Trick and Silverman 1991), in detecting motion direction (Ball and Sekuler 1986; Bennett et al 2007), in speed discrimination (Norman et al 2003), in perception of 3D structure from motion (Andersen and Atchley 1995), and in second-order motion perception (Habak and Faubert 2000). However, little is known about how aging affects biological-motion perception, and studies thus far have reported conflicting results (Billino et al 2008; Norman et al 2004; Pilz et al 2010). Biological motion refers to a movement pattern characteristic of humans and animals (Johansson 1973). Stimuli are constructed solely from points of light placed on the major joints of the body, and yet human observers can recognize complex actions spontaneously from these animations. Furthermore, observers can extract various characteristics from these point-light walkers, such as actions (Dittrich 1993), gender (Jokisch et al 2006; Pollick et al 2005; Troje 2002; Troje et al 2006), identity (Jokisch et al 2006; Troje et al 2005; Westhoff and Troje 2007), and emotion (Dittrich et al 1996).

During our daily activities, different properties of motion must be integrated to provide us with a complete picture of our environment. When navigating through a city or walking through crowds, it is necessary to build a representation of our environment and to anticipate the distance and motion direction of objects and people in order to avoid collision. In these
cases, an important characteristic is the ability to integrate environmental information across our visual field. The visual-field area over which observers can extract information while dividing attention is defined by the useful field of view (UFOV). Research has shown that the UFOV is smaller in older adults compared to younger adults (Fiorentino 2008; Sekuler et al 2000), and that this reduction in visual field is associated with natural tasks such as driving vehicles. Furthermore, the UFOV appears recoverable by training (Edwards et al 2009). Most studies of biological-motion perception use patterns subtending approximately 6 deg of visual angle (dva), which corresponds to an average-sized person located at 16 m from the observer in real life (Bertenthal and Pinto 1994; Billino et al 2008; Jokisch et al 2006; Norman et al 2004; Troje and Westhoff 2006). In real-world scenarios, we are confronted with walkers at all distances. Biological motion located closer to the observer has the same amount of information but is distributed over a larger spatial extent, and therefore over a larger retinal area. Consequently, the performance of younger and older adults should differ, in that older adults would be worse when the same information is to be integrated over a larger area, as suggested by previous studies on visual perception and aging (Edwards et al 2009; Faubert 2002; Fiorentino 2008; Sekuler et al 2000).

It follows from these arguments to expect an age-related decline in biological-motion perception at closer distances. The main purpose of the present study was to assess whether performance differs when biological-motion patterns are located at different distances (in virtual space) that correspond to large differences in retinal image size, and whether these differences interact with the normal aging process.

We use a task in which younger and older adults are required to indicate the direction that point-light walkers face when shown in profile view and masked by additional moving noise dots.

2 Method

2.1 Participants

Ten younger (mean age 29 ± 4.94; range 20–34 years old) and 10 older observers (mean age 67.8 ± 3.71 years; range 64–74 years old) naïve to the purpose of the experiment participated in this study. All subjects had a corrected visual acuity of 20/20 with normal stereovisual acuity as measured by the Frisby test. Testing was binocular. For the older participants, a pair of 1 diopter lenses was added to their usual refractive correction to compensate for accommodation at a testing distance of 1 m. Younger adults were mostly optometry students and reported that they had their most recent eye exam within the last year. Older participants underwent a complete optometric exam at the University optometry clinic less than 6 months before testing. The complete eye exam included refraction, visual fields, tonometry, and retinal exam under pupil dilatation. No ocular pathology was found, and all had normal visual fields. Furthermore, older observers completed the Mini-Mental State Exam (Folstein et al 1975), a screening measure for cognitive impairment and dementia. All subjects’ scores were within the normal range (range 26–30/30; subject mean 29.6/30) (Crum et al 1993). Therefore, they were all considered cognitively healthy.

2.2 Hardware and stimuli

2.2.1 Apparatus. Biological-motion perception was assessed using a Cave Automatic Virtual Environment (CAVE) system, that is, a fully immersive virtual environment (Greffou et al 2008; Piponnier et al 2009). It consisted of an 8 × 8 × 8 feet room that included three canvas projection walls (one frontal and two lateral) and an epoxy floor, all of which served as surfaces for image projection. Four high-resolution projectors were synchronized, and the image was updated in real time to maintain the true viewing perspective of the observer (no false parallax). The CAVE was equipped with a magnetic motion tracker system (Flock-of-
Birds, Ascension Technology Corporation) capable of measuring head position and therefore correcting for the individual’s viewing perspective in real-time. The CAVE was controlled by an SGI ONYX 3200 computer (two Infinite Reality 2 graphics cards) generating a stereoscopic environment. Stereoscopic vision was made possible by the use of stereographics’ LCD stereo shutter glasses (Crystal Eyes; StereoGraphics) operating at 96 Hz.

2.2.2 Stimuli. Stimuli consisted of two components, a walker and a noise mask. The point-light walkers were dynamic representations of a walking human form and were composed of 15 black dots, which represented the head, shoulders, hips, elbows, wrists, knees, and ankles on a white background. Each dot had a diameter of 0.1 m in virtual 3D space: for this dot size to be maintained in 3D space, the 2D size varied inherently. The height of the walker was 1.80 m and was displayed at a virtual distance from the observer of 0.5, 1, 2, 4, and 16 m, therefore subtending 122, 84, 48, 25, and 6.4 deg of visual angle (dva), respectively. For each trial, the walker’s position was randomly jittered within the noise display area (see next paragraph) by 30 cm to the left or right of the central presentation. Walkers were presented walking leftward or rightward. Furthermore, depending on the condition, walkers were either upright or inverted. The walker stimulus was constructed using the average motion-capture data of 50 male and 50 female walkers. For a full explanation of the generation and representation of the stimuli, see Troje (2008). Each gait-cycle duration was 1 s and contained 30 frames. The interstimulus interval was 500 ms.

The walker was masked by noise dots, the number of which varied from trial to trial. The mask consisted of a scrambled walker generated by scrambling the initial spatial position of each dot; as such, the motion of individual noise dots resembled that of individual dots in the intact walker. This made for noise that was appropriate to the stimulus, as the walker and noise mask could be separated only by integrating the walker’s biological motion, and not by differences in individual dot elements. The size and appearance of all dots (noise and walker) were identical. A virtual box surrounding the stimulus was created, within which the noise was contained. Each box volume was 3.70 m$^3$ ($x = 2.10$ m, $y = 2.20$ m, and $z = 0.80$ m). These dimensions were in virtual space, and therefore all appropriate cues changed with experimental distance conditions (ie, size, binocular disparity, and perspective cues).

2.3 Procedure

First, participants were familiarized with the virtual environment and the stimulus. They were then asked to wear the stereoscopic goggles, which allowed them to perceive the 3D characteristics of the environment. Each participant sat 1.20 m from the CAVE’s central wall with an eye height set at 1.60 m from the ground. Participants were asked to look straight ahead. A practice block was then presented with 20 trials in which the participant had to identify the direction of the unmasked walker. Two blocks of each orientation (upright and inverted) were completed before starting the experiment.

The number of noise dots was varied from trial to trial to obtain noise thresholds: how much noise participants can tolerate in order to discriminate the walking direction. Noise thresholds were evaluated using a two-up one-down staircase procedure (Levitt 1971), that is, after two consecutive correct responses, the dependent variable (number of noise dots) was increased by 10% and decreased by the same proportion after each incorrect response, resulting in a threshold criterion of 70.7%. The staircase was interrupted after 10 inversions, and thresholds were estimated by the mean number of noise dots at the last six inversions. As in the practice trial, each observer’s task involved identifying the walker’s direction (right or left) by pressing the left or right key on a joystick. Conditions were presented in random order.
3 Results

Our results for younger adults revealed that performance varied with distance for the upright condition but not for the inverted condition, as indicated by a significant interaction between distance (0.5, 1, 2, 4, and 16 m) and condition (upright or inverted, $F(4, 45) = 3.450, p = .015$) and a weak main effect of distance, $F(4, 45) = 2.582, p = .05$. The effect of distance in the upright condition was driven entirely by the half-meter condition (all $p$ values <.05 for 0.5 m compared to each of the other distances, and all $p$ values >.8 for the longer distances compared to each other). As per the significant interaction of distance and condition mentioned above, the younger observers’ performance was better for upright than for inverted walkers at all distances except 0.5 m. Older observers also exhibited this inversion effect at 16 m, $F(1, 3) = 8.055, p = .023$. We were unable to run any statistics at closer distances (2 and 4 m) for the elderly, because thresholds could not be reached in the inverted condition where performance was too poor. We did obtain, however, thresholds in the upright condition, maintaining the trend that performance is better for upright than for inverted walkers. When comparing older and younger groups, older adults generally tolerated less noise than younger adults at all distances (see Figure 1), and only two older observers could perform the task at distances closer than 2 m, and none at 0.5 m and 1 m. The confidence interval (95%) for tolerable noise quantity in younger observers was 32–121 noise dots at 2 m; the two older observers who were able to complete the task fell outside this range (5 and 25 noise dots). As such, we compared older and younger adults who could reach criterion levels of tolerable noise quantity in the upright condition at distances of 4 and 16 m only (most older participants were able to complete the task in this range). We obtained a significant main effect of age, $F(1, 18) = 61.30, p < .001$, where noise interferes more with older adults than with younger adults.

![Figure 1](image)

**Figure 1.** Younger and older adults' tolerable noise quantity for upright and inverted (younger adults only) walking-direction discrimination task.

Certain conditions were extremely difficult with noise: few or no older participants were able to complete the task with noise at the closer distances (0.5, 1, and 2 m), and many younger adults were unable to complete the inverted condition or the 0.5 m upright condition with noise. For this reason, we calculated the percentage of participants who obtained a 75%
correct performance level when no noise was added to the image (Figure 2). Figure 2a shows that fewer younger participants obtained this minimum performance level for the nearer distances (0.5, 1, and 2 m) than for the longer distances (4 and 6 m). Figure 2b shows that the number of older participants who reached the performance criterion decreased with nearer distances. For the upright condition, the majority of older adults were unable to reach the criterion performance for distances closer than 4 m. For the inverted condition, we obtained a pattern similar to that for younger adults, where the number of observers reaching the performance criterion increased with distance.

![Figure 2. Number of (a) younger and (b) older participants obtaining 75% correct answers for a walking-direction discrimination task, in the no-noise upright and inverted conditions.](image)

Our results are consistent with the two hypotheses initially projected. First, the size of the retinal image, which was tested by the different distances in virtual space, is important for the integration of biological-motion patterns in the upright condition. This is supported by the data at 0.5 m for the younger group and at 2 m and less for the older group, which indicate that observers were unable to tolerate any added noise. We obtained a significant interaction between distance and age, revealing that distance affects older observers to a much larger degree than younger observers. The data also show that older observers have more difficulty processing biological motion in noise. Older adults’ performance began to decrease at a distance of 4 m, compared to younger adults whose performance was stable down to a distance of 1 m. Here, distance is directly related to the size of visual-field stimulation. Note that the results reported here are conservative, in that the true impact of aging is even stronger than shown in these graphs, because a number of older participants were unable to complete the task at near distances.

4 Discussion

In the current study, we projected our 3D stimuli at five different virtual distances. This range of distances allows for the stimulus to span varying extents of our visual field, and therefore different retinal sizes. At near distance, stimuli are large (122 dva at 0.5m) and cannot be perceived holistically: observers must rely on local information to identify the direction of the biological-motion pattern embedded in the scrambled mask. Accordingly, observers exhibit less noise tolerance at closer distances. By using a scrambled walker as a mask, local cues cannot be relied upon, because the local information in the mask and in the walker is identical. In other words, at near distances, observers rely on local information, but in the presence of noise, this information is insufficient to perceive the walker robustly. Furthermore, a walker’s feet constitute an important cue for extracting the direction of
motion (Troje and Westhoff 2006). In our experiment, at near distance and assuming central fixation, the feet fell in the peripheral visual field. It has been shown that peripheral vision is efficient at perceiving biological motion but is weak in the presence of noise, presumably because the visual system is poor at signal–noise segregation in the peripheral parts of the visual field (Thompson et al 2007; see also Gurnsey et al 2008).

In our study, observers had to segregate the figure (biological-motion pattern) from the ground (scrambled mask) for the walker to be perceived. A study by Stanford and Pollack (1984) looked at noise segregation in aging and reported that figure–ground segregation was severely impaired in older adults. Our data support this effect of age on signal–noise segregation. Moreover, segregating signal from noise increases the complexity of a task, which generally leads to stronger effects of age on the task (Faubert 2002). When using scrambled masks, stimuli are processed in two steps: first, the figure is segregated from the ground, and then, motion direction is determined. The present task is a complex motion task, requiring multiple processing steps for its analysis, and this type of task is known to be impaired in aging (Habak and Faubert 2000).

Consistent with previous studies, we report that biological-motion perception is orientation-specific, in that performance is better for upright than for inverted (upside-down) walkers (Bertenthal and Pinto 1994; Pavlova and Sokolov 2000; Sumi 1984; Troje 2003), and may persist for older observers (Pilz et al 2010), although we cannot speak to this directly in our results. This inversion effect is generally attributed to global representations learned in a particular orientation, such as upright faces and the well-documented face-inversion effect, first noted by Yin (1969) and reviewed by Valentine (1988), which is also maintained with age (Boutet and Faubert 2006). The advantage for upright walkers in biological motion appears to break down at very close distances (0.5 m), however. Our data indicate that at 0.5 m, the inversion effect was no longer noted, because thresholds were similar for the inverted and upright conditions. At this distance, the stimulus spanned 122 dva; integration of biological motion might not be possible over such an expanse, and discrimination would be constrained to local cues and analysis.

In conclusion, our results have demonstrated an age-related deficit in perceiving biological motion, which deteriorates further in the presence of noise. Older adults are less resistant to noise and tolerate significantly smaller numbers of noise dots compared to younger adults. Furthermore, older adults require more distance in virtual space between themselves and the point-light walker for them to integrate biological-motion information. This suggests that older adults’ deficits arise from poor spatial integration of biological-motion cues over larger areas, and that an older person’s use of biological-motion information could be inadequate when moving through a crowd or driving in dense circulation, within 4 m. This could explain why navigation can prove difficult for older observers, which in turn could lead to a reduced sense of autonomy. It would be very interesting to determine whether this capacity can be trained in older observers as is the case for UFOV (Richards et al 2006) and 3D-multiple object tracking (Legault et al 2011).

Acknowledgements. This work was supported by the NSERC-Essilor Chair and NSERC discovery funds. We thank Claudine Habak for helpful suggestions on the manuscript.

References

Andersen G J, Atchley P, 1995 “Age-related differences in the detection of three-dimensional surfaces from optic flow” Psychology & Aging 10 650–658

Ball K, Sekuler R, 1986 “Improving visual perception in older observers” Journal of Gerontology 41 176–182
Bennett P J, Sekuler R, Sekuler A B, 2007 “The effects of aging on motion detection and direction identification” *Vision Research* 47 799–809 doi:10.1016/j.visres.2007.01.001

Bertenthal B I, Pinto J, 1994 “Global processing of biological motions” *Psychological Science* 5 221–225 doi:10.1111/j.1467-9280.1994.tb00504.x

Billino J, Bremmer F, Gegenfurtner K R, 2008 “Differential aging of motion processing mechanisms: evidence against general perceptual decline” *Vision Research* 48 1254–1261 doi:10.1016/j.visres.2008.02.014

Boutet I, Faubert J, 2006 “Recognition of faces and complex objects in younger and older adults” *Memory & Cognition* 34 854–864 doi:10.3758/BF03193432

Crum R M, Anthony J C, Bassett S S, Folstein M F, 1993 “Population-based norms for the Mini-Mental State Examination by age and educational level” *JAMA: The Journal of the American Medical Association* 269 2386–2391 doi:10.1001/jama.1993.03500180078038

Dittrich W H, 1993 “Action categories and the perception of biological motion” *The Gerontologist* 39 485–494 doi:10.1093/geront/gnp042

Dittrich W H, Troschanko T, Lea S E, Morgan D, 1996 “Perception of emotion from dynamic point-light displays represented in dance” *Perception* 25 727–738 doi:10.1067/mpe.1996.738

Edwards J D, Myers C, Ross L A, Roenker D L, Cissell G M, McLaughlin A M, Ball K K, 2009 “The longitudinal impact of cognitive speed of processing training on driving mobility” *The Gerontologist* 49 464–470 doi:10.1093/geront/gnp045

Fiorentino D D, 2008 “Cognition, but not sensation, mediates age-related changes in the ability to monitor the environment” *Psychology and Aging* 23 665–670 doi:10.1037/a0013285

Folstein M F, Folstein S E, McHugh P R, 1975 “ ‘Mini-mental state’ . A practical method for grading the cognitive state of patients for the clinician” *JAMA: The Journal of the American Medical Association* 224 145–146 doi:10.1001/jama.1975.032107100450

Gimbels M, Leshem K, 1990 “Postural monitoring and control in an ecological environment” *The Gerontologist* 30 221–227 doi:10.1093/geront/30.3.221

Habak C, Faubert J, 2000 “Larger effect of aging on the perception of higher-order stimuli” *Vision Research* 40 1219–1229 doi:10.1016/S0042-6989(99)00235-7

Habak C, Faubert J, 2000 “Larger effect of aging on the perception of higher-order stimuli” *Vision Research* 40 943–950 doi:10.1016/S0042-6989(99)00235-7

Johansson G, 1973 “Visual perception of biological motion and a model for its analysis” * Perception & Psychophysics* 14 201–211 doi:10.3758/BF03212378

Jokisch D, Daum I, Troje N F, 2006 “Self-recognition versus recognition of others by biological motion: viewpoint-dependent effects” *Perception* 35 911–920 doi:10.1068/p5550

Legault I, Allard R, Faubert J, 2002 “Visual perception and aging” *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale* 56 164–176 doi:10.1037/h0087394

Levitt H, 1971 “Transformed up-down methods in psychoacoustics” *The Journal of the Acoustical Society of America* 47 467–477 doi:10.1121/1.1912375

Norman J F, Payton S M, Long J R, Hawkes L M, 2004 “Aging and the perception of biological motion” *Psychology and Aging* 19 219–225 doi:10.1037/0882-7974.19.1.219

Norman J F, Ross H E, Hawkes L M, Long J R, 2003 “Aging and the perception of speed” *Perception* 32 85–96 doi:10.1068/p3478

Pavlova M, Sokolov A, 2000 “Orientation specificity in biological motion perception” * Perception & Psychophysics* 62 889–899 doi:10.3758/BF03212075

Pilz K S, Bennett P J, Sekuler A B, 2010 “Effects of aging on biological motion discrimination” *Vision Research* 50 211–219 doi:10.1016/j.visres.2009.11.014

Pollick F E, Kay J W, Heim K, Stringer R, 2005 “Gender recognition from point-light walkers” *Journal of Experimental Psychology: Human Perception and Performance* 31 1247–1265 doi:10.1037/0097-129X.31.6.1247

Richards E, Bennett P J, Sekuler A B, 2006 “Age related differences in learning with the useful field of view” *Vision Research* 46 4217–4231 doi:10.1016/j.visres.2006.06.011
Aging and biological-motion perception

Sekuler A B, Bennett P J, Mamelak M, 2000 "Effects of aging on the useful field of view" Experimental Aging Research 26 103–120 doi:10.1080/036107300243588

Stanford T, Pollack R H, 1984 "Configuration color vision tests: the interaction between aging and the complexity of figure–ground segregation" Journal of Gerontology 39 568–571

Sumi S, 1984 "Upside-down presentation of the Johansson moving light-spot pattern" Perception 13 283–286 doi:10.1068/p130283

Thompson B, Hansen B C, Hess R F, Troje N F, 2007 "Peripheral vision: good for biological motion, bad for signal noise segregation?" Journal of Vision 7 12–12 doi:10.1167/7.10.12

Trick G L, Silverman S E, 1991 "Visual sensitivity to motion: age-related changes and deficits in senile dementia of the Alzheimer type" Neurology 41 1437–1440

Troje N F, 2002 "Decomposing biological motion: a framework for analysis and synthesis of human gait patterns" Journal of Vision 2 371–387 doi:10.1167/2.5.2

Troje N F, 2003 "Reference frames for orientation anistropies in face recognition and biological-motion perception" Perception 32 201–210 doi:10.1068/p3392

Troje N F, 2008 "Retrieving information from human movement patterns" in Understanding Events: How Humans See, Represent, and Act on Events Ed. T F Shipley and J M Zacks pp 308–334 (New York: Oxford University Press)

Troje N F, Sadr J, Geyer H, Nakayama K, 2006 "Adaptation aftereffects in the perception of gender from biological motion" Journal of Vision 6 850–857 doi:10.1167/6.8.7

Troje N F, Westhoff C, 2006 "The inversion effect in biological motion perception: evidence for a 'life detector'" Current Biology 16 821–824 doi:10.1016/j.cub.2006.03.022

Troje N F, Westhoff C, Lavrov M, 2005 "Person identification from biological motion: effects of structural and kinematic cues" Perception & Psychophysics 67 667–675 doi:10.3758/BF03193523

Valentine T, 1988 "Upside-down faces: a review of the effect of inversion upon face recognition" British Journal of Psychology 79 471–491 doi:10.1111/j.2044-8295.1988.tb02747.x

Westhoff C, Troje N F, 2007 "Kinematic cues for person identification from biological motion" Perception & Psychophysics 69 241–253 doi:10.3758/BF03193746

Yin R K, 1969 "Looking at upside down faces" Journal of Experimental Psychology 81 141–145 doi:10.1037/h0027474