Peripheral vision: Good for biological motion, bad for signal noise segregation?

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Biological motion perception, having both evolutionary and social importance, is performed by the human visual system with a high degree of sensitivity. It is unclear whether peripheral vision has access to the specialized neural systems underlying biological motion perception; however, given the motion component, one would expect peripheral vision to be, if not specialized, at least highly accurate in perceiving biological motion. Here we show that the periphery can indeed perceive biological motion. However, the periphery suffers from an inability to detect biological motion signals when they are embedded in dynamic visual noise. We suggest that this peripheral deficit is not due to biological motion perception per se, but to signal/noise segregation.

Keywords: biological motion, peripheral vision, noise segregation

Citation: 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*(10):12, 1–7, http://journalofvision.org/7/10/12/, doi:10.1167/7.10.12.

Introduction

The ability of human observers to use the natural movements of animate creatures, referred to as biological motion, to extract complex information has been well documented in central vision. For example, by viewing point light displays, where the only information available is a set of dynamic dots representing the joints of an actor, observers can accurately perceive the actor's gender (Jordan, Fallah, & Stoner, 2006; Mather & Murdoch, 1994; Pollick, Kay, Heim, & Stringer, 2005; Troje, 2002; Troje, Sadr, Geyer, & Nakayama, 2006), recognize emotional states (Clarke, Bradshaw, Field, Hampson, & Rose, 2005; Dittrich, Troscianko, Lea, & Morgan, 1996), recognize individuals as well as themselves (Jokisch, Daum, & Troje, 2006; Troje, Westhoff, & Lavrov, 2005), and identify the specific activity being carried out (Dittrich, 1993). This highly developed perceptual ability is underpinned by a specialized neural system, generally thought to be localized at the superior temporal sulcus (Grèzes et al., 2001; Grossman, Battelli, & Pascual-Leone, 2005; Grossman et al., 2000; Pelphrey, Morris, Michelich, Allison, & McCarthy, 2005; Servos, Osu, Santi, & Kawato, 2002), which presumably exists because of the significant advantages the accurate perception of biological motion provides in terms of both survival and social interaction.

In this context, it is reasonable to assume that biological motion perception would generalize to a larger area of the visual field than just central vision. Indeed, Thornton and Vuong (2004) found that unmasked point light walkers, acting as flanking stimuli presented at eccentricities of up to 5°, could influence the perception of the walking direction of a centrally presented point light display. This suggests that peripheral vision can extract walker direction information and that this processing does not require focused attention. However, a direct investigation into the ability of peripheral vision to perceive biological motion conducted by Ikeda, Blake, and Watanabe (2005) has shown that for a specific set of task parameters peripheral vision is impaired at perceiving biological motion.

Ikeda et al. (2005) measured detection thresholds for point light stimuli that depicted a number of different actions. By embedding the point light displays in masks constructed of scrambled point light stimuli, which effectively mask the individual dot trajectory information in the display (Bertenthal & Pinto, 1994), and by varying the number of noise dots present in the mask, Ikeda et al. showed that detection thresholds were raised when the displays were presented at eccentricities varying from 4° to 12°. Importantly, spatial scaling of the stimuli was

doi: 10.1167/7.10.12 Received February 13, 2007; published July 25, 2007 ISSN 1534-7362

unable to equate performance with foveal presentation, suggesting that peripheral vision could not utilize the biological motion mechanisms available to central vision (however, see Gurnsey, Poirier, Bluett, & Leibov, 2006).

The task used by Ikeda et al. (2005) specifically targets aspects of biological motion perception that emphasize global processing. The ability to detect biological motion in a scrambled walker mask (SWM) requires global integration of the dots constituting the walker and subsequent segregation of the resulting figure from the noise dots. All information carried by the trajectories of individual walker dots is effectively removed by the presence of the SWM. Therefore, it is possible that only the global processes are impaired in the visual periphery rather than biological motion perception per se. This hypothesis would be consistent with the findings reported by Gibson, Sadr, Troje, and Nakayama (2005), who showed that in the absence of noise, performance on biological motion tasks could be equated across the visual field if stimuli were correctly scaled in size.

Although global processing has been found to be important for biological motion perception, it has been shown that biological motion processing also involves local processes (Mather, Radford, & West, 1992). Particularly important to the current study are recent findings that suggest the human visual system uses visual invariants in the trajectories of individual dots to detect terrestrial locomoting animals in the visual environment (Troje & Westhoff, 2006). These authors found that walking direction could be successfully discriminated even when the dots making up a point light display were spatially scrambled. This ability was preserved when the phase and the frequency relations between individual dots were scrambled but inverting the scrambled displays impaired performance. The foot dots were shown to be particularly important in this inversion effect. It is therefore possible that peripheral vision, while unable to perform the complex segregation and integration required for detecting point light displays embedded in scrambled walker noise, is able to use information carried by individual dot trajectories to detect specific motion characteristics of living creatures and recover complex information (e.g., walking direction). Furthermore, Gurnsey et al. (2006) have recently shown that given sufficient size scaling, peripheral vision can accurately perceive 3D structure from motion as well as central vision. As 3D structure from motion is critically dependent on global integration, but not so much on figure-ground segregation; it is possible that the latter process caused the poor performance of the observers of Ikeda et al. (2005).

The current study was designed to provide further insight into perception of biological motion in the periphery by assessing (1) the ability of peripheral vision to process spatially scrambled biological motion and (2) the relative signal/noise segregation abilities of peripheral and central vision (i.e., the segregation of the biological motion signal from different types of visual noise). Following Troje and Westhoff (2006), in Experiment 1 the ability of observers to judge the walking direction of both scrambled and coherent human walkers was measured in peripheral vision. The results indicated that peripheral vision was able to utilize individual dot trajectory patterns to extract complex information from scrambled point light displays in the absence of masking dots. To explain this result in the context of previous studies, Experiment 2 consisted of detection tasks that were conducted using different types of masks to assess the ability of peripheral vision to extract point light displays from noise. Three mask types were used, constructed from (1) scrambled walkers, (2) linearly moving dots, and (3) flickering dots. These masks were chosen as they allow different types of information to be provided by the point light displays. SWMs mask individual dot trajectories leaving only global information about the walker available, whereas linear masks allow both individual dot trajectory information and global information to be used by the observer (Bertenthal & Pinto, 1994). Flicker masks were included as they contain no coherent motion information but do provide a measure of crowding effects. In both experiments, walkers were shown both upright and inverted to test for inversion effects.

Method

Apparatus

Stimuli were presented on a 22-in. Iiyama Vision Master pro 513 monitor, at a screen resolution of 1024 × 768 pixels, with an 85-Hz refresh rate. One pixel subtended 0.048° of visual angle. Stimuli were presented using the Psychophysics Toolbox for Matlab (Brainard, 1997; Pelli, 1997) running on a PC equipped with an Intel 945G integrated graphics controller.

Participants

Four participants, including two authors (B.T. and B.C.H.) took part in both experiments. All subjects had normal or corrected to normal vision. All subjects were experienced psychophysical observers and gave informed consent to participate in all experiments.

Stimuli

Stimuli consisted of two components, a walker and a mask. The mask was presented within a 9.6 × 9.6° visual angle area. The walker was presented within the mask area and was made up of 11 white dots (102.6 cd/m^2)

presented on a dark (0.2 cd/m^2) background. Each dot was square with a width of 0.1°. The height of the walker subtended 7°. This size of walker was chosen as it was considered to be large enough to not disadvantage peripheral vision at 10° eccentricity and also, based on the data of Ikeda et al. (2005), to not significantly disadvantage central vision either. 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 (2002). Participants viewed the stimuli binocularly, either centrally (with the 7° tall stimulus falling within the central portion of the visual field) or at 10° eccentricity, from a distance of 65cm in a darkened room. No fixation point was used for central vision as it was found to interfere with the display dots. For peripheral viewing, a fixation dot subtending 0.4° was placed 10° laterally from the center of the stimulus display upon which observers fixated. All observers were experienced at maintaining fixation.

Walkers were presented facing left or right with no translation (as if walking on a treadmill), upright or inverted, and scrambled or coherent. In the scrambled condition, the phase relationships between the dots were left intact, but the spatial position of each dot was randomly located within an area 7.7° × 2.9°. From trial to trial, walker position was jittered within the noise display up to 1.4° left or right of and 0.72° above or below central presentation. In the inverted condition, walkers were mirror flipped about a horizontal axis.

Three types of mask were used in this study, an SWM, a linear mask, and a flicker mask, all of which were constructed from the same dot elements as the walker stimuli. The SWM was generated by taking walker stimuli and scrambling the spatial positions of each of the dots within the stimulus area. The phases of the mask dots were also scrambled to provide a mask constructed of individual elements moving along the same trajectories as the target walker, but with no coherent spatial or temporal relation to one another. Linear masks were constructed from smoothly linear drifting dots with each dot moving in a random direction at a speed chosen at random from the speeds present in the walker itself. Mask dots had an unlimited lifetime and were randomly replaced within the mask area if they reached the edge of the display. Finally, flicker masks were constructed from a field of randomly positioned static dots with a limited lifetime of 500 ms. See auxiliary files for stimulus examples.

Design and procedure

Two types of task were used, direction discrimination in Experiment 1 and biological motion detection in Experiment 2. Following Troje and Westhoff (2006), for direction discrimination a walker was presented and participants indicated whether the walking direction was left or right using a computer keyboard. The stimuli were presented until the participant responded. Reaction times (RTs) were recorded (RTs exceeding 10 s were excluded from subsequent analysis). Within a block of 180 trials, scrambled and coherent stimuli were randomly interleaved; however, the orientation of the stimuli (upright or inverted) was kept constant throughout a block. Walkers were presented within a mask constructed of linearly moving noise dots. Six dot densities were randomly interleaved within a block with each density being presented 30 times. Dot densities were 0, 25, 47, 87, 161, and 300 dots. One block of trials was run per condition (upright or inverted walker, central or peripheral viewing), and the order of the blocks was randomized across subjects.

For the biological motion detection task, we used a 2AFC paradigm whereby two stimuli, each lasting 2000 ms, were shown consecutively with a 500-ms ISI. Participants were required to identify which stimulus contained a walker using one of two keys on the computer keyboard. In the stimulus interval without a walker, 11 additional noise dots were added to equate noise density. For the SWM condition, these additional dots were confined to the area of the display that would have contained the walker to avoid any local dot density differences. For the linear and flicker mask condition, the dots were randomly added to the mask area. Within a block of 180 trials, six noise densities (30, 43, 61, 88, 126, and 180 noise dots) were randomly interleaved with each density being presented 30 times. Walker orientation (upright or inverted) and mask type (SWM, linear mask, and flicker mask) were kept constant throughout a block. Each block was repeated once for each condition (upright or inverted walker, SWM, linear mask or flicker mask, and central or peripheral viewing). The order of blocks was randomized across subjects.

Data were analyzed using ANOVAs, and degrees of freedom were adjusted using the reasonably conservative Huynh–Feldt correction. Effect sizes were calculated using Cohen's *f*.

Results

The results for the direction discrimination task are shown in Figure 1. Figure 1A shows the average performance for centrally and peripherally presented stimuli without any masking dots. A three-way repeated measures ANOVA (Eccentricity × Inversion × Spatial scrambling) showed no main effect of eccentricity (central vs. peripheral, $F(1, 3) = 3.42$, $p > .05$), no main effect of inversion (upright vs. inverted, $F(1, 3) = 1.12$, $p > .05$), and no main effect of spatial scrambling (coherent vs. scrambled, $F(1, 3) = 4.0$, $p > .05$). There were no significant two- or three-way interactions. These results demonstrate that in unmasked conditions, performance was basically at ceiling and

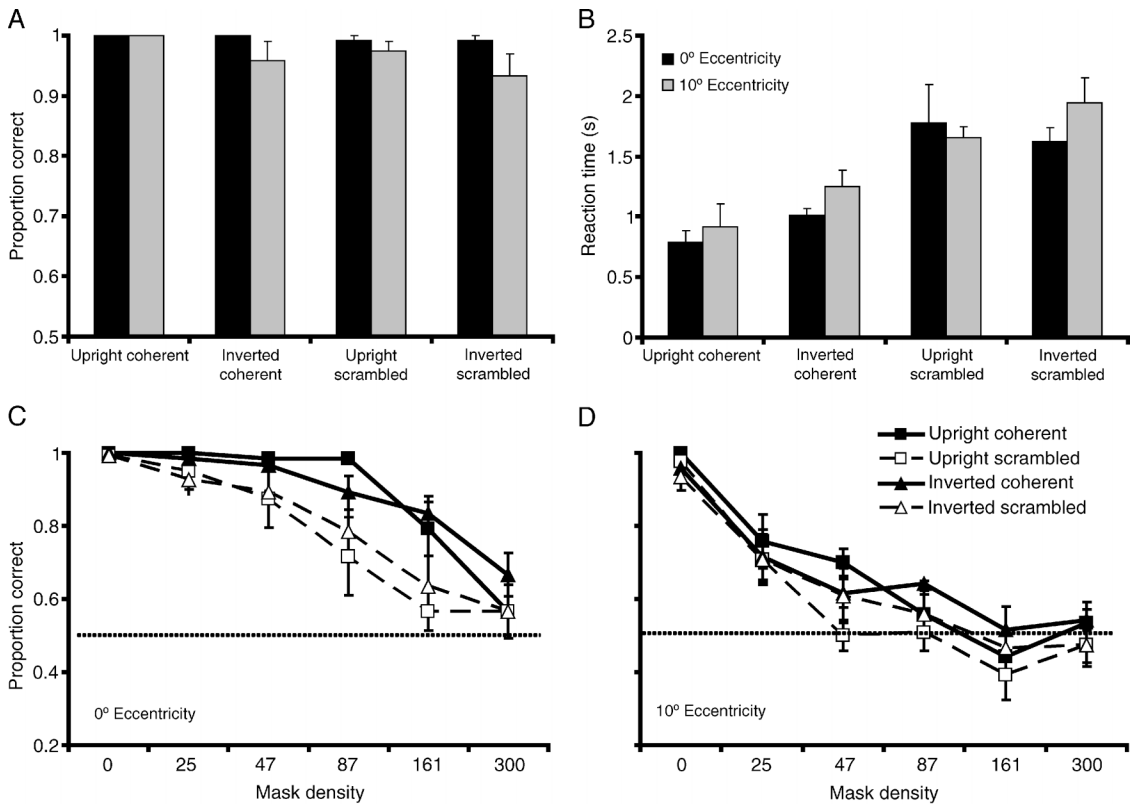

Figure 1. Average accuracies for direction discrimination. Panel A shows the proportion of correct responses for both central and peripheral vision when no noise mask was present. Panel B shows corresponding mean RTs for these conditions. Panels C and D show average proportion correct for stimuli presented in central (C) and peripheral (D) vision as a function of mask dot density. The zero noise density data in panels C and D are the same as that shown in panel A. Error bars show ±1 *SEM* and dashed lines show chance (50% correct) performance.

observers could judge the walking direction of a walker (scrambled or coherent) in peripheral vision just as well as in central vision. An analysis of the RTs for these data, plotted in Figure 1B, showed that central vision was faster at performing this task than peripheral vision, $F(1, 3) = 122.08$, $p < .01$, $f = 40.67$, suggesting that although able to perceive biological motion, the periphery is not as efficient as central vision for these stimuli, with exception of the upright scrambled condition. RT data were analyzed post hoc due to the unanticipated close to ceiling performance in the no mask condition and are longer than one would normally expect, likely due to the fact that the task was not explicitly speeded. Figure 1C shows the effect of adding a mask of linearly moving noise dots to both the scrambled and coherent stimuli in central vision. A three-way repeated measures ANOVA (Inversion × Spatial scrambling × Mask dot density) showed significant main effects of spatial scrambling, $F(1, 3) = 30.05$, $p < .05$, $f = 9.99$, mask dot density $F(2, 5) = 45.95$, $p < .01$, $f = 15.39$, and a significant interaction between spatial scrambling and mask dot density, $F(4, 12) = 4.15$, $p < .05$, $f = 1.34$. There was no main effect of inversion, $F(1, 3) = 0.12$, $p > .05$, and no other significant two- or three-way interactions. Therefore, for the central direction discrimination task, performance decreased as a function of mask dot density and this decrease was more pronounced for the scrambled stimuli than the coherent stimuli, suggesting that form from motion information present in the coherent stimuli made them more resilient to the addition of noise dots. The results for peripheral vision are shown in Figure 1D in the same manner as Figure 1C. It is clear from a comparison of Figures 1C and 1D that once noise dots were added, performance fell off more rapidly in the periphery than in central vision. A three-way repeated measures ANOVA (Inversion × Spatial scrambling × Mask dot density) conducted on the peripheral data showed significant main effects of spatial scrambling, $F(1, 3) = 13.64$, $p < .05$, $f = 4.56$, and mask dot density, $F(4, 11) = 41.35$, $p < .001$, $f = 13.71$. For peripheral viewing, there was no significant interaction between spatial scrambling and mask dot density, $F(5, 15) = 0.29$, $p > .05$; in fact there were no significant two- or three-way interactions for this analysis. The performance of the direction discrimination task in the periphery was therefore sensitive to whether the stimuli were spatially scrambled; however, this effect was smaller than that observed for central vision. Furthermore, the effect of spatial scrambling did not interact with mask dot density for peripheral vision, suggesting that the effect of spatial scrambling was not exacerbated by noise as was the case for central vision.

To compare the effect of spatial scrambling in central vision with that in the periphery, we fitted a logistic function to each participant's data and calculated 75% correct thresholds for the scrambled and the coherent walkers. Fitting and threshold calculation was performed using Psignifit (Wichmann & Hill, 2001a, 2001b). A comparison of the threshold differences between coherent and scrambled walkers for central and peripheral vision showed that scrambling had a greater effect on central vision thresholds than peripheral for both upright, $t(3) = 4.43$, $p < .05$, and inverted, $t(3) = 4.42$, $p < .05$, displays.

To summarize the results from the first experiment, biological motion direction discrimination was equally accurate in central and peripheral vision in the absence of noise although peripheral RTs were greater. The addition of noise reduced performance for both central and peripheral vision; however, there was no interaction between noise density and whether the stimulus was spatially scrambled for peripheral vision. In addition, the effect of spatial scrambling was less pronounced for peripheral vision than for central vision, suggesting that central vision is better able to utilize the configural information present in a coherent stimulus.

The results from the second experiment, designed to measure the ability of central and peripheral vision to detect biological motion embedded in different types of masks, are shown in Figure 2. Figure 2A shows the central vision performance for both an SWM and a linear mask. It is clear from this figure that the SWM greatly influences task performance whereas linear masking has little effect over the range of noise densities used in the current experiments. Flicker masking had no effect on task performance in central vision and was therefore excluded from the analysis. A three-way repeated measures ANOVA revealed significant main effects of mask type (scrambled walker vs. linear, $F(1, 3) = 24.64$, $p < .05$, $f = 8.17$), inversion (upright vs. inverted, $F(1, 3) = 32.12$, $p < .05$, $f = 10.76$), and mask dot density, $F(5, 15) = 18.90$, $p < .001$, $f = 6.30$. There was a significant interaction between mask type and mask dot density, $F(3, 10) = 16.81$, $p < .001$, $f = 5.62$, and a marginal interaction between mask type and inversion, $F(1, 3) = 9.56$, $p = .054$, $f = 3.18$. Interactions involving mask type for these data reflected the fact that performance with the linear mask was at ceiling. No other two- or three-way interactions were significant. Therefore, for central vision, the addition of noise dots influenced task performance more for the SWM than the linear dot mask. Task performance for detection in the periphery is shown in Figure 2B. The data in Figure 2B clearly differ from that in Figure 2A. Task performance for biological noise is worse in the periphery than in central vision. For the linear mask performance is equivalent for both viewing conditions at low-noise densities; however, performance rapidly drops off with increasing mask density for peripheral viewing. A three-way ANOVA showed significant main effects of mask type (scrambled walker vs. linear vs. flicker, $F(2, 5) = 21.66$, $p < .01$, $f = 7.20$) and mask dot density, $F(2, 4) = 23.32$, $p < .01$, $f = 7.77$; however, there was no main effect of inversion, $F(1, 3) = 0.37$, $p > .05$. There was a significant interaction between mask type and mask dot density, $F(3, 8) = 8.16$, $p < .01$, $f = 2.22$, with all other interactions being nonsignificant. These results show that the three different types of noise differentially influenced task performance in the periphery. In addition, the effect of inversion was different between central and peripheral vision, a finding consistent with previous reports (Ikeda et al., 2005).

Discussion

The results suggest that (1) for the specific task and stimuli used in Experiment 1, biological motion can be

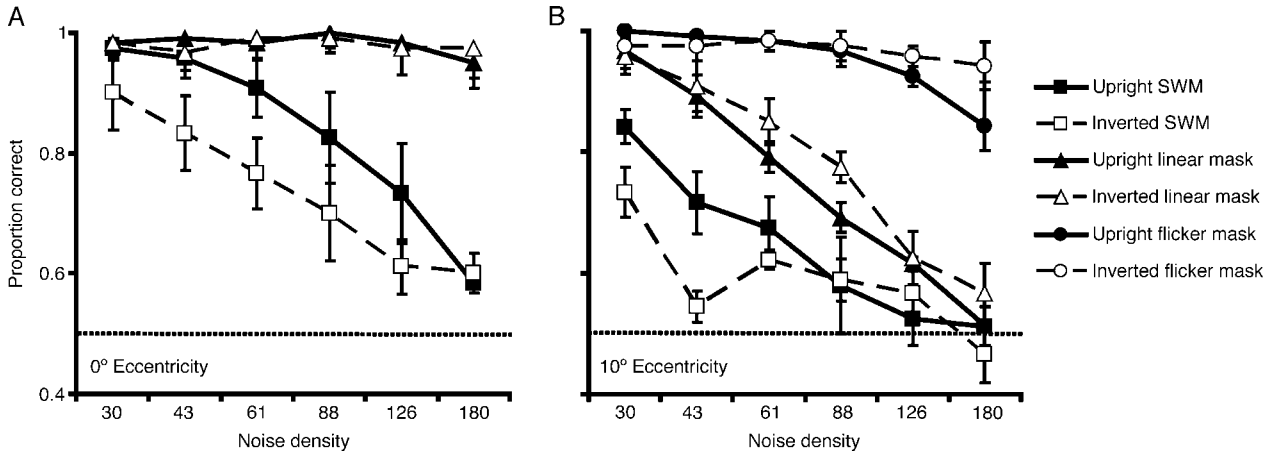

Figure 2. Mean accuracies for point light walker detection. Graphs show the proportion of correct detections as a function of mask density (number of dots) for central viewing (A) and peripheral viewing (B). SWM stands for scrambled walker mask. Error bars show ± *SEM* and dashed lines show chance (50% correct) performance. For clarity, flicker mask performance for central vision is not shown as performance was at ceiling.

perceived just as accurately in the periphery as in central vision in the absence of noise, and (2) for walker detection, the periphery is more sensitive to the addition of masking dots than central vision. For both central and peripheral vision, the effectiveness of a mask appears to be contingent on how well the masking dots degrade the individual dot trajectories present in the biological motion display, supporting previous studies (Bertenthal & Pinto, 1994).

The finding that when using peripheral vision we are able to accurately perceive the walking direction of point light displays in the absence of noise (scrambled or coherent) suggests that the periphery can process biological motion information even in the absence of configural cues. However, the periphery did require more time than central vision to perform the task, with the exception of the upright scrambled walker condition, showing that although accuracy is unimpaired, the periphery is slower relative to central vision in the time taken to perform the task. Support for the hypothesis that peripheral vision has a greater reliance on local dot trajectory patterns for biological motion perception can be found in the relatively small influence that spatial scrambling had on task performance as mask density increased compared to central vision. We did not find a pronounced inversion effect for the scrambled stimuli as has previously been reported (Troje & Westhoff, 2006). This was likely due to the use of a blocked design, which may have led observers to use different strategies for the upright and inverted stimuli and the fact that the participants were experienced psychophysical observers.

The second experiment, which investigated the relative influence of masking dots on central and peripheral perception of point light walkers, showed that peripheral vision is impaired in making the required figure ground segregations to allow for biological motion perception in a noisy background. The specific finding that peripheral vision was particularly impaired at detecting a point light walker in SWN and that task performance for this condition did not reach levels comparable to central vision supports the findings of Ikeda et al. (2005). The effect of the linear dot mask was much more pronounced in the periphery than in central vision where it had very little effect even at the highest density. Therefore, for this particular task, peripheral vision is much more sensitive to linear noise than central vision. It is possible that local dot density differences facilitated walker detection for the linear mask condition as, due to the nature of the mask, additional masking dots in the walker-absent stimulus were randomly allocated within the display area and were not confined to the portion of the display which would have contained the walker. At the higher noise densities, however, where local dot density would be less useful as a discrimination cue, it is likely that the nonlinear local trajectories of walker dots provided the strongest discrimination information. Finally, flicker noise had very little impact on task performance in the periphery. This suggests that the effects observed for scrambled walker and linear masks in the periphery were not just due to crowding resulting from the presence of additional dots in the display but were related to the motion characteristics of the masks themselves. This is an important point because crowding has been shown to be more pronounced in the periphery (Latham & Whitaker, 1996). It is also evident from a comparison of the two experiments that linear noise dots influenced discrimination performance (Experiment 1) more than detection (Experiment 2) in central vision. This may be because linear masks do not effectively mask the distinctive motion trajectories of individual walker dots, which are sufficient for detection, but may not always provide enough unambiguous information for accurate discrimination performance.

By using both discrimination and detection paradigms, an attempt was made to test a range of biological motion tasks; however, given that different cues and strategies can be used to perceive biological motion depending on the task and the stimulus (Beintema, Georg, & Lappe, 2006), it is difficult to generalize to other biological motion perception tasks and stimuli.

The current results are consistent with those reported by Gibson et al. (2005), who found that size scaling could equate biological motion performance in the absence of noise, and those of Ikeda et al. (2005), who showed that size scaling could not equate performance in the presence of noise, as they indicate that that the way in which noise influences performance is different between central and peripheral vision. One major difference between this study and the work of Ikeda et al. is the use of a single action (walking) in this study and the use of multiple actions by Ikeda et al., which may have made the susceptibility to noise even more pronounced in the periphery than that demonstrated here. Ikeda et al. do suggest that under different conditions peripheral vision may not show such pronounced deficits, a hypothesis supported by this study when those conditions relate to different types of masking techniques.

In conclusion, our results suggest that the periphery is impaired at segregating signal from noise, a manipulation often used to quantify sensitivity in biological motion tasks using coherent walkers. Further studies are required to ascertain why the periphery is poor at signal segregation.

Acknowledgments

This research was supported by CIHR grant number MOP 10808 the RFH, NSERC grant number 298198-05, and CFI project grant number 201705 to NFT.

Commercial relationships: none.
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