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Effects of walker gender and observer gender on biological motion walking direction discrimination

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Abstract: The ability to recognize the movements of other biological entities, such as whether a person is walking toward you, is essential for survival and social interaction. Previous studies have shown that the visual system is particularly sensitive to approaching biological motion. In this study, we examined whether the gender of walkers and observers influenced the walking direction discrimination of approaching point-light walkers in fine granularity. The observers were presented a walker who walked in different directions and were asked to quickly judge the walking direction (left or right). The results showed that the observers demonstrated worse direction discrimination when the walker was depicted as male than when the walker was depicted as female, probably because the observers tended to perceive the male walkers as walking straight ahead. Intriguingly, male observers performed better than female observers at judging the walking directions of female walkers but not those of male walkers, a result indicating perceptual advantage with evolutionary significance. These findings provide strong evidence that the gender of walkers and observers modulates biological motion perception and that an adaptive perceptual mechanism exists in the visual system to facilitate the survival of social organisms.

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A vivid perception of the moving form of a human figure can be obtained from a few light points attached to the head and the major joints of a walker (Johansson, 1973). The sensitivity of the human visual system to this type of stimuli, namely, point-light biological motion, is very general and acute (Thornton, 1998). Human observers can readily tell the walking direction (Thompson, Hansen, Hess, & Troje, 2007; Troje & Westhoff, 2006), gender (Kozlowski & Cutting, 1977; Pollick, Kay, Heim, & Stringer, 2005; Troje, 2002a), emotional state (Dittrich, Troscianko, Lea, & Morgan, 1996; Montepare, Goldstein, & Clausen, 1987), and even personality traits (Cutting & Kozlowski, 1977; Loula, Prasad, Harber, & Shiffrar, 2005) of point-light walkers simply on the basis of these sparse motion and configural cues. Among them, walking direction provides critical information on the disposition and intention of other people (Shi, Weng, He, & Jiang, 2010). Previous studies have found that observers can discriminate the walking direction of point-light walkers even when these walkers are embedded in dynamic visual noise (Bertenthal & Pinto, 1994; Neri, Morrone, & Burr, 1998; Thurman & Grossman, 2008) or are presented in peripheral vision (Thompson et al., 2007), and that the walking direction can even be processed incidentally (Thornton & Vuong, 2004). A recent study has also shown that the visual system is particularly sensitive to approaching biological motion (Sweeny, Haroz, & Whitney, 2012), which presumably reflects an evolved and adaptive perceptual mechanism to facilitate the survival of social organisms (Blake & Shiffrar, 2007). However, whether this superior sensitivity is modulated by the social characteristics of the walkers and the observers, such as gender information, remains to be fully elucidated.

Recent studies have examined the role of gender information in the perceived in-depth orientation of point-light walkers. An orthographically projected point-light walker is ambiguous with regard to depth, such that it can be perceived as either facing (walking) toward or away from observers. Stimulus manipulation that makes a point-light walker appear masculine has also been shown to make the walker appear more likely to walk toward rather than away from observers; this result has been explained as an evolved perceptual bias (i.e., facing bias) to warn organisms about potential threats (Brooks et al., 2008). Moreover, a significant interaction between walker gender and observer gender has been demonstrated: The facing bias for male point-light walkers appeared to be stronger for male than for female observers (Schouten, Troje, Brooks, van der Zwan, & Verfaillie, 2010). However, the facing bias is based on a special perceptual phenomenon (i.e., bistable perception) rather than common visual information processing, so drawing a general conclusion about biological motion perception is difficult. Moreover, because an orthographically projected point-light walker is a completely depth-ambiguous stimulus, the interpretation of the in-depth orientation and the constitution of the facing bias might be highly dependent on the experience of the observers as well as their response criteria. More importantly, the relation between perceived walker gender and facing bias is not causal because structural and kinematic stimulus manipulations that induce comparable changes in perceived walker gender could produce opposite changes in perceived in-depth orientation (Schouten, Troje, & Verfaillie, 2011). In other words, whether and to what extent the walker gender and the observer gender influence biological motion perception remains to be elucidated.

We hence examined this issue using a typical task on walking direction discrimination which has been widely adopted to explore biological motion perception (Cai, Yang, Chen, & Jiang, 2011; Chang & Troje, 2008; Gurnsey, Roddy, & Troje, 2010; Jiang & He, 2008; Kuhlmeier, Troje, & Lee, 2010; Saunders, Williamson, & Troje, 2010; Sweeny et al., 2012). Previous studies have explored the influence of low-level stimulus properties, such as motion speed, on walking direction discrimination; the current study focused on the potential role of social and biological properties in the perception of walking direction. We aimed to further examine the effects of walker gender and observer gender on biological motion walking direction discrimination. In comparison with the ambiguous in-depth facing orientation judgment, the task on walking direction discrimination is considered a basic perceptual process of the visual system, and is less susceptible to response bias (Aaen-Stockdale, Thompson, Hess, & Troje, 2008; Cai et al., 2011; Neri et al., 1998; Shi et al., 2010; Thompson et al., 2007; Thornton & Vuong, 2004; Troje & Westhoff, 2006). Even 6-month-old infants have been reported to possess the ability to differentiate the walking direction of an upright human point-light walker (left vs. right; Kuhlmeier et al., 2010).

Methods

Participants

A total of 80 undergraduate students (39 female observers with a mean age of 22.3 ± 0.49 years and 41 male observers with a mean age of 23.07 ± 0.53 years) took part in the current study. Of these, 37 observers (17 female) participated in Experiment 1, 12 observers (six female) in Experiment 2, and 31 observers (16 female) in Experiment 3. A total of six observers (two female) were excluded from Experiment 1 because they could not consistently perceive the point-light walker as walking toward the front direction (see below for details). They all had normal or corrected-to-normal vision and gave written informed consent in accordance with procedures and protocols approved by the institutional review board of the Institute of Psychology, Chinese Academy of Sciences. They were all naïve to the purpose of the experiments.

Stimuli and procedure

Visual stimuli were generated and displayed on a 20-in. CRT monitor screen with the use of MATLAB (Mathworks, Inc.), together with Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). Point-light biological motion sequences were adopted from previous studies (Troje, 2002b; Troje, Sadr, Geyer, & Nakayama, 2006). The gender of the point-light walkers was gradually manipulated on the gender continuum described in detail by Troje (2002b). This continuum is indexed by a *Z* score from the average (or gender-neutral) walker. For instance, a point-light walker with a *Z* score of +1 means a walker who appears masculine and is 1 *SD* away from the mean, whereas a *Z* score of −1 indicates a walker who looks feminine and is 1 *SD* away from the mean. Five sets (with *Z* scores of −2, −1, 0, 1, and 2) of point-light walkers were chosen and used in the current study, and these sets corresponded to the walkers who were strongly feminine, weakly feminine, gender neutral, weakly masculine, and strongly masculine, respectively (see Figure 1A). Each set of biological motion stimuli also included a number of side walking directions with ±2, ±4, and ±6 deg in angular

Figure 1. Static frames of sample stimuli in Experiment 1. (A) A total of five sets of point-light walkers, corresponding to the walkers who are strongly feminine, weakly feminine, gender neutral, weakly masculine, and strongly masculine, were used in Experiment 1. (B) Each set of biological motion stimuli also included the front direction and a number of side walking directions with ±2, ±4, and ±6 deg in angular rotation from the front direction.

rotation from the front direction (0 deg), along with the front direction itself (see Figure 1B). Each motion cycle was set to 1 s.

The stimuli appeared white on a grey background, and the viewing distance was approximately 70 cm. In Experiment 1, each trial began with fixation on a central cross (0.8 × 0.8 deg), followed by a point-light walker that subtended 4.3 × 10.7 deg of the visual angle and appeared in the center of the screen. A small random spatial displacement (0–1 deg) was adopted with the presentation of the point-light walker to avoid any potential interference effect from previous trials. The point-light walker was presented for 1 s, and the initial frame of the point-light display was randomized for each test stimulus and for each trial. After the stimulus was presented, the observers were asked to make a forced choice to indicate as accurately as possible whether the walker was walking toward the left or the right side from the front direction. To minimize the potential effect of variations caused by the inconsistency of perceived in-depth heading orientation (forward vs. backward; Cavanagh, Labianca, & Thornton, 2001; Sweeny et al., 2012), those participants who could not perceive the point-light walker as walking consistently toward the front were excluded. The observers pressed one of two keys on a standard keyboard regardless of the gender of the walker. A total of 20 trials were used for each condition (5 walker gender conditions × 7 walking direction conditions), with the order of test conditions randomized for each trial and for each observer.

Experiment 2 was designed to further test whether the difference in sensitivity to walking direction discrimination observed in Experiment 1 could be attributed to the manner by which the observers tended to perceive the walker as facing toward the front direction when the walker was depicted as masculine. We repeated the procedure of Experiment 1, except that an additional option was given to the observers. The responses of the observers could therefore be "left," "right," or "the front direction." Three walker gender conditions were tested in this experiment, namely, strongly masculine, gender neutral, and strongly feminine. All other aspects were the same as those in Experiment 1.

Experiment 3 was designed to test whether male and female observers perceived the gender of the point-light walkers differently. In this experiment, observers were asked to report whether the gender of the walker was male or female, instead of the walking direction, by pressing one of two keys on a standard keyboard. As observers showed near-perfect gender judgments with the original sets of the stimuli used in Experiment 1, we had to choose a narrower gender range to examine if there was any subtle difference in the perceived walker gender between male and female observers. Accordingly, seven additional sets (from −0.45 *SD* to +0.45 *SD*, with intervals of 0.15 *SD*) of point-light walkers with the front direction and ±6 deg in angular rotation from the front direction were used as test stimuli. All other aspects were the same as those in Experiment 1.

Data analyses

For Experiments 1 and 3, all data points from the forced choice task were fit with a Boltzmann sigmoid function $[f(x) = 1/(1 + \exp((x - x_0)/\omega))]$ for each observer (Holmes, 2007; Wang & Jiang, 2012; Figure 2A). Measurement of the discriminability of the biological motion walking direction was indexed by the difference limen (DL), which is estimated by the interquartile range of the fitted function ($DL = x_{0.75} - x_{0.25}$). In other words, a smaller DL indicates the higher discriminability of the observer. In addition, the point of subjective equality (PSE), which is estimated by the midpoint of the Boltzmann function, was obtained to measure the point at which the observer perceived a walker as

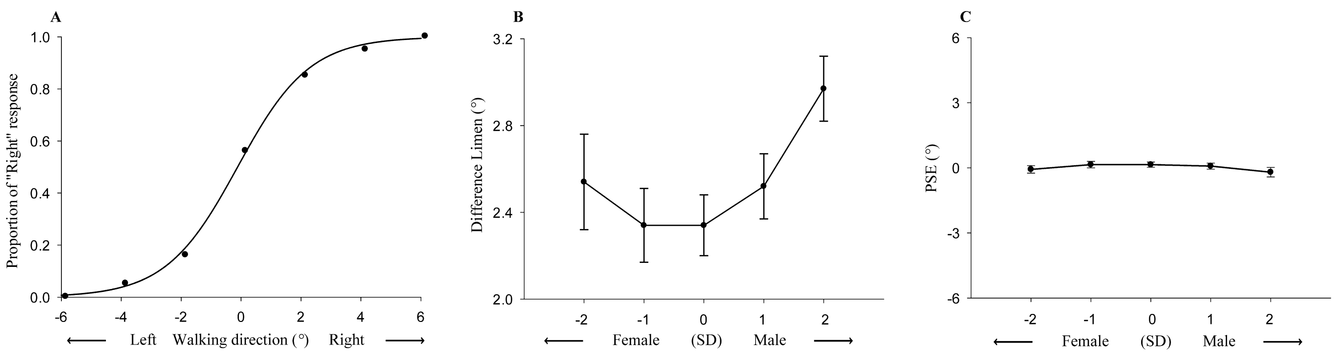

Figure 2. (A) Psychometric function for a typical observer in a walking direction judgment task. The graph shows the proportion of "the right direction" response as a function of the point-light walker's walking direction. (B) The mean difference limen (DL) values under different walker gender conditions in Experiment 1. Observers showed worse direction discrimination when the walker was depicted as strongly masculine. (C) The mean point of subjective equality (PSE) values in different walker gender conditions. There was no significant effect of walker gender on observers' PSE of the walking direction discrimination. Error bars indicate standard error. *$p < .05$.

walking in the front direction. The PSE and DL values were then subject to further group averaging and statistical tests. A two-way mixed-design repeated measures ANOVA was conducted, with the walker gender (strongly feminine, weakly feminine, gender neutral, weakly masculine, and strongly masculine) being the within-subject factor and the observer gender (female and male) being the between-subject factor. For Experiment 2, the proportion of "the front direction" response was calculated for each walker gender condition (strongly masculine, gender neutral, and strongly feminine). A one-way ANOVA was conducted for the walker gender condition. A large response proportion would indicate that the observers are likely to perceive the walker as walking toward the front direction. Correction for multiple comparisons (Bonferroni correction) was performed for all post hoc tests.

Results

Results of Experiment 1

The DL and PSE values averaged across all observers are plotted in Figures 2B and 2C, respectively. A two-way mixed-design ANOVA, with the walker gender as the within-subject factor and the observer gender as the between-subject factor, showed a significant main effect of the gender of the point-light walker on observer discriminability (DL) of the walking direction, $F(4, 116) = 4.32$, $p < .005$, $\eta^2_p = .135$. Further post hoc tests showed that the DL value was significantly larger for the walker who appeared strongly masculine ($Z = +2$) than for the other walkers (ps $< .05$, corrected for multiple comparisons; Figure 2A). Observers showed the worst discrimination sensitivity to the biological motion walking direction when the point-light walker was depicted as strongly masculine. Moreover, walker gender had no significant effect on the observer PSE of walking direction discrimination, $F(4, 116) = 1.79$, $p > .1$, $\eta^2_p = .056$, a result which suggests that gender information did not bias observer judgment toward the left or the right walking direction (Figure 2C). The main effect of observer gender was not significant for DL, $F(1, 29) = 2.84$, $p > .1$, $\eta^2_p = .089$, or PSE, $F(1, 29) = 0.03$, $p > .8$, $\eta^2_p = .00$.

Interestingly, the interaction between the observer gender and the walker gender was significant for the observer discriminability, $F(4, 116) = 2.47$, $p < .05$, $\eta^2_p = .078$. The DL value for each test condition is plotted in Figure 3. Independent samples t-tests showed significant differences between male and female observers when the point-light walker was depicted as strongly feminine, $t(29) = 2.20$, $p < .05$, $\eta^2_p = .132$, or weakly feminine, $t(29) = 2.02$, $p < .05$, $\eta^2_p = .123$. Male observers showed better performance than female observers on the walking direction discrimination of female walkers but not on that of neutral or male walkers. Although female and male observers seem to show different overall trend patterns, further analyses revealed that there was no significant trend for female ($R^2 = 0.072$ for the quadratic polynomial test) or male observers ($R^2 = 0.097$ for the linear polynomial test). Again, no main effect or interaction was found for observer PSE values, $F(4, 116) = 1.71$,

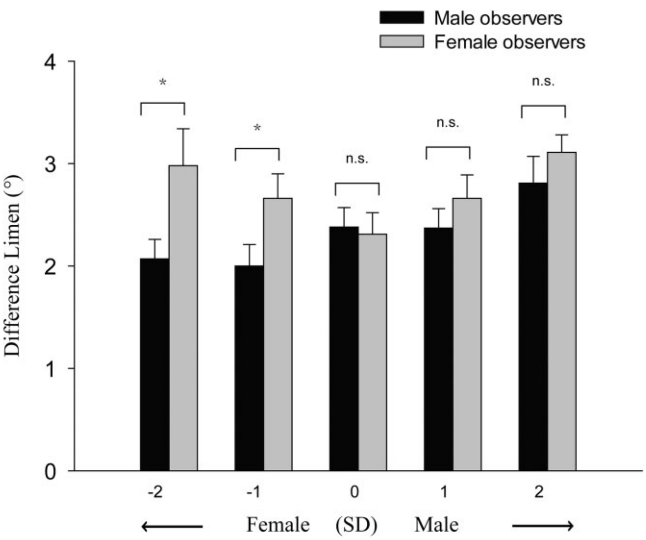

Figure 3. The mean difference limen (DL) values of female and male observers under different walker gender conditions in Experiment 1. Male observers showed better direction discrimination when the walker was depicted as feminine. Error bars indicate standard error. n.s. = no significance. $^{*}p < .05$.

$p > .1$, $\eta^2_p = .01$, and $F(4, 116) = 0.20$, $p > .1$, $\eta^2_p = .00$, respectively.

Result of Experiment 2

In Experiment 1, observers demonstrated worse direction discrimination when the walker was depicted as male than when the walker was depicted as female. It is possible that the observers tended to perceive the male walker as walking or facing straight ahead, as it potentially conveys important social information (Brooks et al., 2008; Lin, Murray, & Boynton, 2009; Schouten et al., 2010). Therefore, Experiment 2 was designed to test this possibility. The proportion of "the front direction" response was plotted as a function of walker gender in Figure 4. A one-way ANOVA indicated a significant walker gender effect on observer judgment, $F(4, 44) = 7.57$, $p < .01$, $\eta^2_p = .511$. Post hoc analysis showed that male point-light walkers were more likely to be perceived as walking toward the front direction (i.e., toward the observers) than gender neutral ($p < .05$, $\eta^2_p = .307$) or female walkers ($p < .01$, $\eta^2_p = .505$). This finding suggests that the walker gender effect found in Experiment 1 was likely caused by an observer tendency to perceive the male walker as walking toward the front direction. In other words, the more masculine the point-light walker appeared, the more responses to the front direction an observer would make and therefore the poorer the direction discrimination performance.

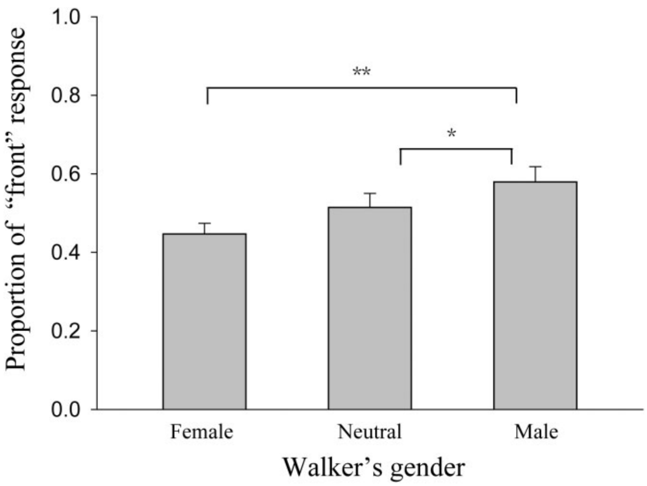

Figure 4. The mean proportions of "the front direction" response under different walker gender conditions in Experiment 2. Male walkers were more likely to be perceived as walking toward the front direction than female and gender neutral walkers. Error bars indicate standard error. $^{*}p < .05$.

Result of Experiment 3

The results of Experiment 1 showed a clear and strong effect of observer gender on the direction discrimination of the point-light walkers. However, it could be argued that this observer gender effect on biological motion perception was due to a different gender perception of the point-light walkers between the male and the female observers. It is possible that female observers generally perceived the point-light walkers as more masculine than did male observers, which would have caused the observed gender effect on biological motion perception in Experiment 1. Therefore, Experiment 3 was designed to test this possibility and observers were asked to judge whether the gender of the walkers was male or female, instead of their walking direction.

A two-way repeated measures ANOVA showed that neither the main effects of the stimulus gender, $F(2, 60) = 0.52$, $p > .5$, $\eta^2_p = .055$, or the observer gender, $F(1, 30) = 0.37$, $p > .5$, $\eta^2_p = .044$, nor the interaction between these two factors, was significant, $F(2, 60) = 0.79$, $p > .4$, $\eta^2_p = .011$, consistent with previous findings (Schouten et al., 2010). These results suggest that the observer gender effect found in Experiment 1 could not be due to perceived gender difference between male and female observers (Figure 5). Rather, there might be an adaptive perceptual mechanism in the visual system that is responsible for the sensitivity difference of biological motion walking direction judgment between female and male observers.

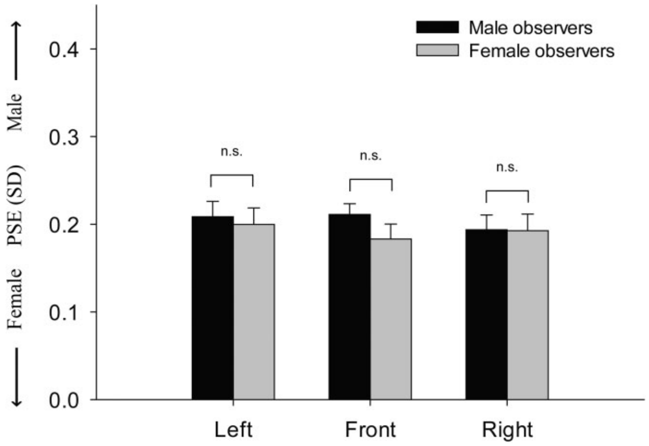

Figure 5. The average point of subjective equality (PSE) values of female and male observers under different walking direction conditions in Experiment 3. Female and male observers did not perceive the gender of the point-light walkers differently. Error bars indicate standard error. n.s. = no significance.

Discussion

In the current study, we adopted a task on walking direction judgment to investigate whether biological motion walker gender and/or observer gender information can modulate biological motion perception. The results from Experiment 1 showed a significant influence of walker gender on biological motion walking direction discrimination. Specifically, observer walking direction discriminability was significantly worse for male walkers than for female walkers, a result indicating the possibility of a perceptual tendency of observers to perceive a male walker as walking or facing straight ahead. We further explored this issue in Experiment 2 and confirmed that observers were more likely to perceive male than female walkers as walking toward the front direction (i.e., toward the viewer) rather than orienting to side directions (Lin et al., 2009). A possible explanation for this outcome is that male walkers usually convey important social information, such as threat, which might need the observers' immediate attention or reaction (e.g., fight or flight; Brooks et al., 2008; Schouten et al., 2010). Although there was a configural difference (e.g., lateral body sway) between the male and female point-light walkers (Mather & Murdoch, 1994; Pollick et al., 2005; Troje, 2002b), the observed pattern of results was unlikely due to this factor. This is because the observed gender effect was specific to strongly masculine walkers and there was no correlation between the observers' discrimination sensitivity and the gender continuum of the stimuli. Furthermore, a similar effect on facing bias has been demonstrated in previous studies, in which observers perceived the depth-ambiguous point-light stimuli as facing (walking) toward the viewer more often for male than female walkers (Brooks et al., 2008; Schouten et al., 2010).

More intriguingly, we also observed a significant interaction between the gender of the walkers and the gender of the observers, a result indicating that the observer gender further modulated the walker gender effect on biological motion walking direction discrimination. Specifically, male and female observers performed similarly when the walkers were depicted as gender neutral, or weakly and strongly masculine. However, male observers showed significantly better discrimination sensitivity than female observers when female walkers were presented. The observer gender effect was also found in a previous study (Schouten et al., 2011). However, it might be argued that this observer gender effect on biological motion perception was due to a different gender perception of the point-light walkers between the male and the female observers, and thus Experiment 3 was designed to test this possibility. Observers were asked to judge whether the gender of a briefly presented walker was male or female, regardless of the walking direction. The results from this control experiment ruled out the possibility that male and female observers might perceive the gender of the stimuli differently, thereby confirming the significant effect of the observer's gender on biological motion perception. Although the brain mechanism underlying the observer gender effect is not quite clear, we speculate the existence of an adaptive perceptual mechanism in the visual system that is selectively tuned to gender information (Ryan, 1998). By this means, the human visual system may have evolved the perceptual bias such that male observers are more sensitive than female observers to the appearance and motion of female individuals.

In conclusion, this study provides strong evidence that observer sensitivity to biological motion walking direction is modulated by the gender of the walker and the gender of the observer. This finding suggests the existence of an evolved and adaptive perceptual mechanism in the visual system that presumably facilitates the survival of social organisms. Whether the mechanism is general or specific to biological motion perception is worthy of further investigation.

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References

Aaen-Stockdale, C., Thompson, B., Hess, R. F., & Troje, N. F. (2008). Biological motion perception is cue-invariant. *Journal of Vision*, *8*(8), 6. doi:10.1167/8.8.6

Bertenthal, B. I., & Pinto, J. (1994). Global processing of biological motions. *Psychological Science*, *5*(4), 221–225. doi:10.1111/j.1467-9280.1994.tb00504.x

Blake, R., & Shiffrar, M. (2007). Perception of human motion. *Annual Review of Psychology*, *58*, 47–73. doi:10.1146/annurev.psych.57.102904.190152

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, *10*(4), 433–436. doi:10.1163/156856897X00357

Brooks, A., Schouten, B., Troje, N. F., Verfaillie, K., Blanke, O., & van der Zwan, R. (2008). Correlated changes in perceptions of the gender and orientation of ambiguous biological motion figures. *Current Biology*, *18*(17), R728–R729. doi:10.1016/j.cub.2008.06.054

Cai, P., Yang, X., Chen, L., & Jiang, Y. (2011). Motion speed modulates walking direction discrimination: The role of the feet in biological motion perception. *Chinese Science Bulletin*, *56*(19), 2025–2030. doi:10.1007/s11434-011-4528-6

Cavanagh, P., Labianca, A. T., & Thornton, I. M. (2001). Attention-based visual routines: Sprites. *Cognition*, *80*(1–2), 47–60. doi:10.1016/S0010-0277(00)00153-0

Chang, D. H. F., & Troje, N. F. (2008). Perception of animacy and direction from local biological motion signals. *Journal of Vision*, *8*(5), 3. doi:10.1167/8.5.3

Cutting, J. E., & Kozlowski, L. T. (1977). Recognizing friends by their walk: Gait perception without familiarity cues. *Bulletin of the Psychonomic Society*, *9*(5), 353–356. doi:10.3758/BF03337021

Dittrich, W. H., Troscianko, T., Lea, S. E. G., & Morgan, D. (1996). Perception of emotion from dynamic point-light displays represented in dance. *Perception*, *25*(6), 727–738. doi:10.1068/p250727

Gurnsey, R., Roddy, G., & Troje, N. F. (2010). Limits of peripheral direction discrimination of point-light walkers. *Journal of Vision*, *10*(2), 15. doi:10.1167/10.2.15

Holmes, N. P. (2007). The law of inverse effectiveness in neurons and behaviour: Multisensory integration versus normal variability. *Neuropsychologia*, *45*(14), 3340–3345. doi:10.1016/j.neuropsychologia.2007.05.025

Jiang, Y., & He, S. (2008). Neural encoding of walking direction in biological motion: Evidence from direction-specific adaptation and functional neuroimaging. *Journal of Vision*, *8*(6), 902. doi:10.1167/8.6.902

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception and Psychophysics*, *14*(2), 201–211. doi:10.3758/BF03212378

Kozlowski, L. T., & Cutting, J. E. (1977). Recognizing the sex of a walker from a dynamic point-light display. *Perception and Psychophysics*, *21*(6), 575–580. doi:10.3758/BF03198740

Kuhlmeier, V. A., Troje, N. F., & Lee, V. (2010). Young infants detect the direction of biological motion in point-light displays. *Infancy*, *15*(1), 83–93. doi:10.1111/j.1532-7078.2009.00003.x

Lin, J. Y., Murray, S. O., & Boynton, G. M. (2009). Capture of attention to threatening stimuli without perceptual awareness. *Current Biology*, *19*(13), 1118–1122. doi:10.1016/j.cub.2009.05.021

Loula, F., Prasad, S., Harber, K., & Shiffrar, M. (2005). Recognizing people from their movement. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(1), 210–220. doi:10.1037/0096-1523.31.1.210

Mather, G., & Murdoch, L. (1994). Gender discrimination in biological motion displays based on dynamic cues. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *258*(1353), 273–279. doi:10.1098/rspb.1994.0173

Montepare, J. M., Goldstein, S. B., & Clausen, A. (1987). The identification of emotions from gait information. *Journal of Nonverbal Behavior*, *11*(1), 33–42. doi:10.1007/BF00999605

Neri, P., Morrone, M. C., & Burr, D. C. (1998). Seeing biological motion. *Nature*, *395*(6705), 894–896. doi:10.1038/27661

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10*(4), 437–442. doi:10.1163/156856897X00366

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*(6), 1247–1265. doi:10.1037/0096-1523.31.6.1247

Ryan, M. J. (1998). Sexual selection, receiver biases, and the evolution of sex differences. *Science*, *281*(5385), 1999–2003. doi:10.1126/science.281.5385.1999

Saunders, D. R., Williamson, D. K., & Troje, N. F. (2010). Gaze patterns during perception of direction and gender from biological motion. *Journal of Vision*, *10*(11), 9. doi:10.1167/10.11.9

Schouten, B., Troje, N. F., Brooks, A., van der Zwan, R., & Verfaillie, K. (2010). The facing bias in biological motion perception: Effects of stimulus gender and observer sex. *Attention, Perception, and Psychophysics*, *72*(5), 1256–1260. doi:10.3758/App.72.5.1256

Schouten, B., Troje, N. F., & Verfaillie, K. (2011). The facing bias in biological motion perception: Structure, kinematics, and body parts. *Attention, Perception, and Psychophysics*, *73*(1), 130–143. doi:10.3758/s13414-010-0018-1

Shi, J., Weng, X., He, S., & Jiang, Y. (2010). Biological motion cues trigger reflexive attentional orienting. *Cognition*, *117*(3), 348–354. doi:10.1016/j.cognition.2010.09.001

Sweeny, T. D., Haroz, S., & Whitney, D. (2012). Reference repulsion in the categorical perception of biological motion. *Vision Research*, *64*, 26–34. doi:10.1016/j.visres.2012.05.008

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. doi:10.1167/7.10.12

Thornton, I. M. (1998). The visual perception of human locomotion. *Cognitive Neuropsychology*, *15*(6–8), 535–552. doi:10.1080/026432998381014

Thornton, I. M., & Vuong, Q. C. (2004). Incidental processing of biological motion. *Current Biology*, *14*(12), 1084–1089. doi: 10.1016/j.cub.2004.06.025

Thurman, S. M., & Grossman, E. D. (2008). Temporal "Bubbles" reveal key features for point-light biological motion perception. *Journal of Vision*, *8*(3), 28. doi:10.1167/8.3.28

Troje, N. F. (2002a). Decomposing biological motion: A framework for analysis and synthesis of human gait patterns. *Journal of Vision*, *2*(5), 2. doi:10.1167/2.5.2

Troje, N. F. (2002b). The little difference: Fourier based synthesis of gender-specific biological motion. In R. Würtz & M. Lappe (Eds.), *Dynamic perception* (pp. 115–120). Berlin: AKA 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*(8), 7. 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*(8), 821–824. doi:10.1016/j.cub.2006.03.022

Wang, L., & Jiang, Y. (2012). Life motion signals lengthen perceived temporal duration. *Proceedings of the National Academy of Sciences*, *109*(11), E673–E677. doi:10.1073/pnas.1115515109