Atten Percept Psychophys (2011) 73:130–143
DOI 10.3758/s13414-010-0018-1

The facing bias in biological motion perception: structure, kinematics, and body parts

Ben Schouten · Nikolaus F. Troje · Karl Verfaillie

Published online: 25 November 2010

Abstract Depth-ambiguous point-light walkers (PLWs) elicit a facing bias: Observers perceive a PLW as facing toward them more often than as facing away (Vanrie, Dekeyser, & Verfaillie, *Perception, 33*, 547–560, 2004). While the facing bias correlates with the PLW's perceived gender (Brooks et al., *Current Biology, 18*, R728–R729, 2008; Schouten, Troje, Brooks, van der Zwan, & Verfaillie, *Attention, Perception, & Psychophysics, 72*,1256–1260, 2010), it remains unclear whether the change in perceived in-depth orientation is *caused* by a change in perceived gender. In Experiment 1, we show that structural and kinematic stimulus properties that lead to the same changes in perceived gender elicit opposite changes in perceived in-depth orientation, indicating that the relation between perceived gender and in-depth orientation is not causal. The results of Experiments 2 and 3 further suggest that the perceived in-depth orientation of PLWs is strongly affected by locally acting stimulus properties. The facing bias seems to be induced by stimulus properties in the lower part of the PLW.

Keywords Biological motion · Facing bias · Structure · Kinematics · Depth · Ambiguity

Electronic supplementary material The online version of this article (doi:10.3758/s13414-010-0018-1) contains supplementary material, which is available to authorized users.

B. Schouten (✉) · K. Verfaillie
Laboratory of Experimental Psychology, University of Leuven,
Tiensestraat 102,
3000, Leuven, Belgium
e-mail: Ben.Schouten@psy.kuleuven.be

N. F. Troje
Department of Psychology and School of Computing,
Queen's University,
Kingston, Ontario K7M 3N6, Canada

Introduction

Adequately perceiving and understanding the actions of conspecifics for humans is a prerequisite for normal social development and interaction (Gallese, Keysers, & Rizzolatti, 2004). Since the findings of Johansson (1973), point-light figures have proven to be very useful in studying the visual perception of actions or biological motion. Despite the limitation of the visual information to a small number of moving point lights, observers are able to effortlessly judge a variety of behaviorally relevant properties. Verfaillie (2000), Blake and Shiffrar (2007), and Troje (2008) have provided reviews.

Orthographically projected point-light figures are inherently ambiguous with respect to their in-depth orientation. On the basis of the stimulus properties, observers are expected to perceive the figure as facing toward them in half of the cases and as facing away from them in the other half. Vanrie, Dekeyser, and Verfaillie (2004; see Jackson & Blake, 2010, and Jackson, Cummins, & Brady 2008, for related research on the perception of bistable biological motion stimuli), however, demonstrated that this is not what is empirically found when observers have to indicate the perceived in-depth orientation for a set of depth-ambiguous point-light actions. Several point-light stimuli, especially point-light walkers, elicit a strong facing bias. That is, observers perceive the walker as facing toward them in most of the cases (see also Vanrie & Verfaillie, 2008). To date, it is not clear what causes this perceptual bias. One could assume, for instance, that in daily life, observers are more often confronted with a person facing toward them than with a person that is oriented away. There are, however, no natural image statistics available that show that this is indeed the case (Vanrie et al., 2004). Otherwise, it could be hypothesized that a person who is facing toward an observer is more socially or behaviorally relevant for the observer than a person who is oriented away. The facing bias might thus reflect an evolved perceptual bias to err on the side of caution. In other words, perceiving someone who is walking away from you as walking toward you comes with a much lower cost, as compared with misinterpreting someone who is actually walking toward you as walking away.

To explore whether biological or social relevance drives the facing bias, Brooks, Schouten, Troje, Verfaillie, Blanke, and van der Zwan (2008) recently investigated the role of the gender of the point-light walker in its perceived in-depth orientation. Many studies have shown that observers easily pick up on the cues that signal the gender of a point-light figure (see, e.g., Barclay, Cutting, & Kozlowski, 1978; Cutting, 1978; Hiris & Ewing, 2010; Jordan, Fallah, & Stoner, 2006; Kozlowski & Cutting, 1977; Mather & Murdoch, 1994; Pollick, Kay, Heim, & Stringer, 2005; Troje, 2002; Troje, Sadr, Geyer, & Nakayama, 2006; van der Zwan et al., 2009). Assuming that male and female point-light walkers differ in biological or social relevance, male figures might elicit different degrees of the facing bias than do female figures. For instance, an approaching male might be more threatening than an approaching female. Brooks et al. (2008) found a strong effect of figure gender on perceived in-depth orientation. Consistent with Vanrie et al. (2004), male point-light walkers elicited a strong facing bias. However, the more strongly the figure was perceived as female, the more strongly it was perceived as facing away from the viewer. Schouten, Troje, Brooks, van der Zwan, and Verfaillie (2010) further investigated the effect of figure gender and the role of observer sex in a larger sample of male and female observers. While it was much weaker, as compared with what was observed in Brooks et al. (2008), Schouten et al. again observed a significant figure gender effect: Male figures elicited a stronger facing bias than did female figures. Remarkably, Schouten et al. also observed a small but significant interaction between figure gender and observer sex: The facing bias for male point-light walkers appeared to be stronger for male observers than for female observers.

The results of Brooks et al. (2008) and Schouten et al. (2010) might be interpreted as evidence that perceived gender is an important causal variable in the facing bias. However, although both studies demonstrated a correlation between perceived gender and perceived in-depth orientation, they did not show that the relation is causal—namely, that the male figure was perceived as facing the viewer because it was interpreted as a male walker and the female figure was perceived as facing away because it was seen as a female walker. Indeed, particular configural or kinematic stimulus properties that are related to the change in figure gender might, regardless of the perceived gender they elicit, be responsible for the change in perceived in-depth orientation. Vanrie and Verfaillie (2006), for example, have shown that purely kinematic aspects of an action performed by the same male actor strongly affect depth assignment: The presence of a preferred interpretation depends on the performed action. One could thus argue that the hypothesis of a causal link between perceived gender and perceived in-depth orientation becomes less probable when one takes into account the fact that not all male point-light actions elicit a facing bias. Nevertheless, we reasoned that the correlation found in Brooks et al. and Schouten et al. for walking needed to be investigated more directly.

The goal of the present study was therefore to find out whether the change in perceived gender causes the figure gender effect or whether stimulus-based factors bias the perceived in-depth orientation. In Experiment 1, we tested the role of structural and kinematic information. More specifically, we tested whether structural and kinematic variations that lead to the same changes in perceived gender also lead to comparable changes in perceived in-depth orientation. In Experiment 2, we explored whether the facing bias arises from information in a particular part of the stimulus. In particular, we verified whether the upper and lower parts of the point-light figures elicit comparable or different perceived in-depth orientations. In Experiment 3, we investigated the interaction between the variables that were manipulated in Experiments 1 and 2.

Experiment 1

Introduction

If biological or social relevance in terms of perceived gender causes the facing bias, changes in perceived in-depth orientation should be independent of the way the point-light configuration signals gender. Stimulus changes that lead to similar changes in perceived gender should thus lead to similar changes in perceived in-depth orientation. With this in mind, we utilized Troje's (2002) method to decompose the original set of point-light figures into structure-only and kinematics-only point-light figures, signaling gender from extremely female to extremely male. Structure-only stimuli varied only in structural cues (neutral kinematics), whereas kinematics-only stimuli varied only in kinematic cues (neutral structure). Troje (2002) showed that orthographic frontal/back projections of both sets of stimuli lead to a highly comparable perceived gender.

The goal of Experiment 1 was to elicit a comparable change in perceived gender with two types of gender cues: structure and kinematics. If changes in perceived in-depth orientation are caused by changes in perceived gender and both gender cues elicit the same perceived gender, structure-only stimuli should elicit the same change in perceived in-depth orientation as kinematics-only stimuli. If, in such a case, structure-only stimuli and kinematics-only stimuli were to elicit different changes in perceived in-depth orientations, this would suggest that changes in perceived in-depth orientation are not directly caused by changes in perceived gender.

Method

Participants Forty-four psychology students (22 males and 22 females) at the University of Leuven participated for course credit. All the participants had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment. None of them had participated in previous experiments investigating the facing bias.

Stimuli and apparatus From the same set of coordinates as that used in Brooks et al. (2008) and Schouten et al. (2010), two sets of seven stimuli signaling gender from extremely female to extremely male (*z* scores: −6, −4, −2, 0, 2, 4, 6 *SD*) were created: structure-only stimuli and kinematics-only stimuli. The structure of a figure is defined in terms of the average positions of each of the 15 dots over one step cycle. The kinematics of a figure is defined in terms of the trajectory of each dot relative to its average position. Structure-only stimuli were intended to contain only structural differences and no differences in kinematics. Hence, structure-only stimuli were created by keeping the individual structural information of each figure and replacing its kinematics by the kinematics of the neutral figure (see the online Supplemental Video 1). Kinematics-only stimuli were meant to contain only kinematic differences and no differences in structure. So, kinematics-only stimuli were created by keeping the individual kinematics of each figure and replacing its structure by the structure of the neutral stimulus (see the online Supplemental Video 2). For more details on the creation of the stimuli, see Troje (2002) and Troje, Westhoff, and Lavrov (2005). Each point-light walker was orthographically and frontally presented in the center of the screen (subtending a size of 8º of visual angle in height), and each consisted of 15 black dots (radius = 15 arc min of visual angle) on a gray background. Each trial started with a 500-ms fixation cross, followed by the stimulus presentation consisting of three walking cycles (1.5 s per cycle), each consisting of two steps (128 frames per cycle at 85 Hz). Participants could respond only after each stimulus presentation with a keypress (unlimited time). Pressing a response key initiated the next trial. The start position of the animation cycle was randomized across trials.

Procedure All the observers were tested individually. They were seated in a dimly lit and sound-attenuated room in front of a 21-in. CRT monitor. Viewing distance was 57 cm. During instructions, participants were shown an extremely male (6 *SD*), extremely female (−6 *SD*), and neutral (0 *SD*) stimulus. They were instructed to indicate on each trial, by a keypress, whether the presented stimulus was perceived as oriented toward or away from them (arrow down for facing the viewer [FTV], arrow up for facing away [FA]). They were instructed to respond according to their own subjective experience, and it was stressed that an equal distribution of both response alternatives was not necessary. When instructions were clear, participants completed 40 practice trials (random selection of all possible conditions). Then it was checked again whether the task was clear, and the experiment commenced. Both the group of 22 males and the group of 22 females were randomly divided into two groups of 11 participants each. The first group judged the in-depth orientation of the seven structure-only point-light figures in the first half of the experiment and the gender of the same stimuli in the second half. The second group did the same for the kinematics-only stimuli. Observers were informed about what would be the task in the second phase (gender judgments) only after they had completed the first phase (facing judgments). Within each phase, the order of the trials was randomized. In total, each participant completed 420 trials (7 genders * 2 phases * 30 repetitions), divided into six sessions of 35 trials in each phase. Between sessions, participants could take a break. In total, the experiment lasted about 1 hr.

Results

In Fig. 1a, we plot the mean proportions of *male* responses across observers as a function of figure gender for the structure-only stimuli and the kinematics-only stimuli. From the plot, it is clear that, as was demonstrated by Troje (2002), perceived gender of frontally presented point-light figures is highly comparable for structure-only and kinematics-only stimuli.

The proportions of *male* responses as a function of figure gender were fitted with a cumulative Gaussian for structure-only and kinematics-only stimuli separately. Confidence intervals of the means and slopes were computed on the basis of 10,000 Monte Carlo simulations (see Wichmann & Hill, 2001a, 2001b). The slopes of the curves fitted to the proportions of *male* responses for the structure-only stimuli (slope = 0.27; $CI_{.95}$ = [0.25, 0.30]) and the kinematics-only stimuli (slope = 0.32; $CI_{.95}$ = [0.29, 0.36]) do not differ. There is, however, a slight but significant difference in the means of the structure-only (M = −0.76; $CI_{.95}$ = [−0.86, −0.65]) and kinematics-only (M = −1.00; $CI_{.95}$ = [−1.12, −0.89]) curves. Both curves are shifted somewhat to the left, indicating a bias toward responding *male* more often than *female*. This so-

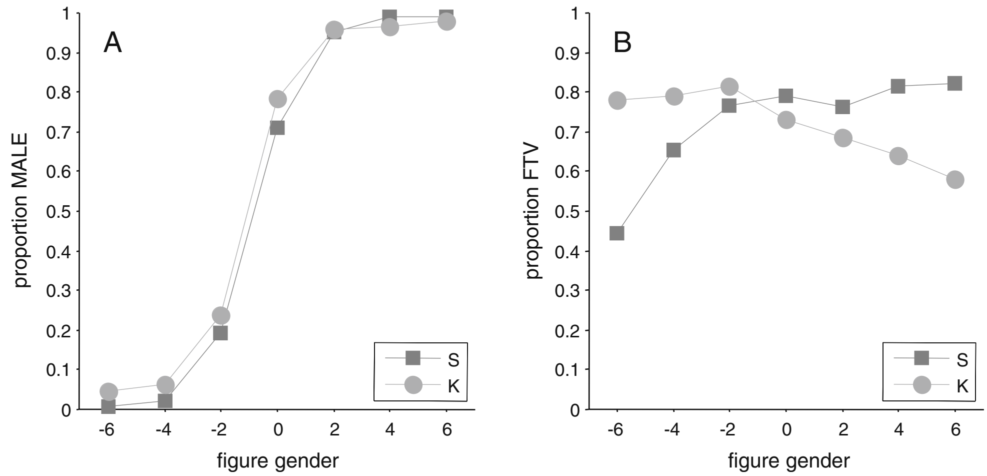

Fig. 1 Proportions of *male* responses (**a**) and proportions of facing-the-viewer responses (**b**) as a function of figure gender (from extremely female, −6 *SD*, to extremely male, 6 *SD*) for structure-only (S) and kinematics-only (K) point-light walkers

called *male bias* has been observed in several studies before (Schouten et al., 2010; Troje & Szabo, 2006; Troje et al., 2006; van der Zwan et al., 2009). Here, the male bias appears to be slightly stronger for kinematics-only stimuli. Taken together, however, we can conclude that changes in proportions of *male* responses as a function of figure gender are highly comparable for structure-only and kinematics-only point-light walkers.

Hence, if a change in perceived in-depth orientation were to be caused by a change in perceived gender, the change in perceived in-depth orientation should be comparable for structure-only and kinematics-only stimuli. An inspection of Fig. 1b, however, reveals an *opposite* relation between perceived gender and perceived in-depth orientation for structure-only stimuli, as compared with kinematics-only stimuli. Thus, stimulus manipulations that give rise to the same change in perceived gender give rise to an opposite change in perceived in-depth orientation.

To analyze the relation between figure gender and perceived in-depth orientation for structure-only and kinematics-only stimuli in more detail, we transformed, for each observer, the proportions of FTV responses for each figure gender to *z* values (probit analysis). We then fitted, for each observer, a second-order polynomial to the probit-transformed FTV responses as a function of figure gender. This returned three meaningful parameters (constant, slope, and curvature) for each observer. This transformation allowed analyses of variance (ANOVAs) and *t* tests on the parameters across observers.

The constant parameter reflects the overall facing bias (across figure gender). A positive value indicates a facing bias. A negative value indicates a tendency to see the figure as facing away. Values near zero (FTV values around 50%) indicate that the figure is perceived as depth ambiguous. The slope parameter represents the slope with which FTV responses change as a function of figure gender. Positive values indicate that the number of FTV responses increases when the figure gender changes from extremely female to extremely male and vice versa. The curvature parameter represents the curvature in FTV responses as a function of figure gender. Negative values indicate that the number of FTV responses for extremely female or extremely male gender figures tend to be smaller than that for gender figures in between.

In Fig. 2, we plot the means and 95% confidence intervals across observers for each of the three parameters, including parameter values for male and female observers separately. First, data for the constant variable indicate that, on average, the structure-only (FTV = 72.21%) and kinematics-only (FTV = 71.78%) stimuli elicit a comparable facing bias. Second and most important, Fig. 2b confirms what was observed in Fig. 1b. Structure-only stimuli elicit an opposite slope, as compared with kinematics-only stimuli. The slope of structure-only stimuli is significantly positive, $t(21) = 4.00$, $p < .001$, and the slope of kinematics-only stimuli is significantly negative, $t(21) = -2.97$, $p = .007$. Third, both types of stimuli elicit negative curvature, significant for the structure-only stimuli, $t(21) = -3.84$, $p < .001$, and a negative tendency for the kinematics-only stimuli, $t(21) = -1.90$, $p = .07$. Although the tendency is not significant, negative curvature is somewhat stronger for structure-only stimuli than for kinematics-only stimuli, $t(21) = -2.0102$, $p = .06$.

From Fig. 2, no strong differences between the parameter values of male and female observers are apparent. This was confirmed by a 2 (gender cue: structure only vs. kinematics only)×2 (observer sex: male vs. female observer) repeated measurement ANOVA on each of the three parameters separately. Only for the constant parameter was a tendency toward an effect of observer sex found, $F(1, 40) = 3.72$, $p = .06$: Male observers (FTV = 76.97%) tended to show a somewhat stronger facing bias than did female observers (FTV = 67.02%). For none of the parameters was an interaction between observer sex and gender cue observed.

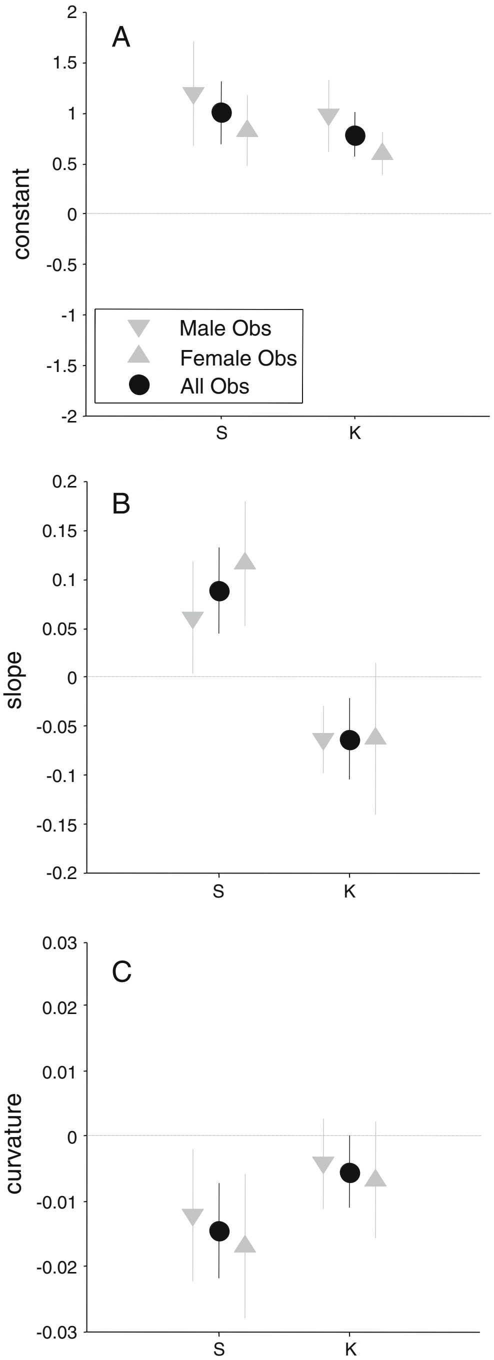

Fig. 2 Mean parameter values and 95% confidence intervals for the second-order polynomial fit on the probit-transformed facing-the-viewer responses as a function of figure gender for structure-only (S) and kinematics-only (K) point-light walkers in Experiment 1. Black circles represent means and confidence intervals across all observers. Gray arrows pointing downward/upward represent the data for male and female observers, respectively

Discussion

As was expected on the basis of the results of Troje (2002), the perceived gender of the frontoparallel projected structure-only and kinematics-only point-light walkers was, apart from the small difference in the means, found to be highly comparable. Hence, under the hypothesis of a causal relation between perceived gender and perceived in-depth orientation, changes in proportions of FTV responses as a function of figure gender for structure-only stimuli and kinematics-only stimuli should also be comparable. The results, however, show that the structure-only stimuli elicited an opposite relation between figure gender and perceived in-depth orientation, as compared with the kinematics-only stimuli. Structure-only stimuli, on average, induced a positive relation between perceived in-depth orientation and figure gender: The facing bias was much stronger for male figures and was absent for female figures. Kinematics-only female stimuli, in contrast, elicited a facing bias, and the more male the figure was, the weaker the facing bias was.

Contrary to what was observed in Schouten et al. (2010), here we did not find a significant interaction between figure gender and observer sex. Note, however, that the interaction found in Schouten et al. resulted from male observers' exhibiting a stronger facing bias than did female observers only for male figures. Although not significant, here male observers tended to show a higher constant than did female observers, indicating a higher facing bias across all gender figures for male observers than for female observers.

The crucial finding of Experiment 1 is that structural and kinematic variations between point-light figures that lead to comparable changes in perceived gender lead to opposite changes in in-depth perceptions. The data thus indicate that the change in facing bias as a function of figure gender that was observed by Brooks et al. (2008) and Schouten et al. (2010) did not result directly from a change in the perceived gender. In contrast, stimulus properties that also lead to changes in perceived gender or that covary with other stimulus properties that lead to changes in perceived gender seem to have played an important role.

Experiment 2

Introduction

The results of Experiment 1 show a strong effect of structural and kinematic stimulus properties on the facing bias. Other stimulus manipulations that globally change the structure or kinematics of the point-light figure, such as perspective cues (Schouten & Verfaillie, 2010; Vanrie et al., 2004) or the type of action (Vanrie & Verfaillie, 2006), have also been demonstrated to affect the facing bias. However, the fact that stimulus manipulations that affect the entire figure also have an effect on the facing bias does not imply that the facing bias arises from information distributed over the entire figure. Some participants in the Schouten et al.

(2010) study, but also in the present Experiment 1, spontaneously reported that, to some degree, the perceived in-depth orientation seemed to depend on the part of the figure that they were attending to. When asked to further describe their impressions, these observers reported that when looking at the lower part, they tended to perceive the figure as facing toward them in most of the cases, whereas when looking at the upper part, the FA interpretation occurred more often. These subjective reports suggest that the facing bias does not arise from information that is distributed over the entire figure but, rather, from information that is present in the lower part of the point-light walker.

Vanrie and Verfaillie (2010) reported preliminary evidence that is in line with these subjective reports, albeit for a jumping action and not for a walking action. Indeed, whereas eye movement recordings of observers reporting switches in the perceived orientation of point-light *walkers* delivered somewhat inconsistent data, eye movement data for observers reporting switches in the in-depth interpretation of a *jumping* point-light figure suggested that fixations in the lower part of the figure resulted in relatively more FTV interpretations and fixations in the upper part of the figure in relatively more FA interpretations. This was the case not only when participants were instructed to freely saccade to a point-light figure presented in the periphery (internally determined initial fixations), but also when the initial fixation location was controlled experimentally by manipulating stimulus appearance, relative to the fixation location (externally determined fixations).

In Experiment 2, we explicitly manipulated the available stimulus information, in order, first, to more directly test the hypothesis that the facing bias in the perception of point-light walkers depends on the figure part observers attend and, second, to examine whether this modulates the correlation between perceived gender and depth orientation. To this end, we included, besides the original point-light figures used in Schouten et al. (2010), two extra conditions in which either only the upper parts or only the lower parts of the point-light walkers were shown. Proportions of FTV responses were recorded.

Method

Participants Fourteen psychology students (7 males and 7 females) from the University of Leuven participated for course credit. All had normal or corrected-to-normal vision and were naïve as to the aims of the experiment. None of them had participated in previous experiments investigating the facing bias.

Stimuli and apparatus Apart from occluding either the upper or the lower part of the walker, stimuli were identical to the stimuli used in Schouten et al. (2010). The gender stimuli thus differed in structural, as well as in kinematic, information. Two variables were manipulated: figure part and figure gender. There were three types of figure part information: Only the upper part, only the lower part, or the whole figure was visible. In the upper-part condition, only 8 dots representing the head, shoulders, sternum, elbows, and wrists were presented. In the lower-part condition, only 7 dots representing the pelvis, hips, knees, and ankles were visible. In the whole-figure condition, all 15 dots were shown. The spatial locations and motions of individual dots in the upper-part and lower-part conditions were exactly the same as those for the dots representing the same body location in the whole-figure condition. As in Schouten et al. and Experiment 1, from the set of 13 gender stimuli (Brooks et al., 2008; Troje, 2002), 7 were chosen so as to be equally spaced between extremely female and extremely male (z scores: −6, −4, −2, 0, 2, 4, 6 *SD*). The factorial combination of figure gender and figure part resulted in 21 different point-light stimuli. Stimulus duration, start position, and randomization method were similar to those in Experiment 1.

Procedure The procedure differed from that in Experiment 1 on the following points. Before the start of the experiment, participants were shown whole extreme male (6 *SD*), extreme female (−6 *SD*), and neutral (0 *SD*) stimuli and were informed that these kind of stimuli or only their upper part or lower part were going to be presented and that their task consisted of reporting whether the figure was seen as facing the viewer or as facing away (arrow down for FTV, arrow up for FA). When instructions were clear, participants completed 40 practice trials (random selection of all possible conditions). For each of the 21 stimulus combinations, the 14 observers completed 20 repeats. Within each observer, all 420 trials were randomized and divided into seven sessions of 60 trials. Between sessions, participants could take a break. In total, the experiment lasted almost 1 hr.

Results

As in Experiment 1, for each observer in each of the figure part conditions (whole, upper only, lower only), the probit-transformed proportions of FTV responses (z values) as a function of figure gender (z values) were fitted with a second-order polynomial, returning a constant, slope, and curvature parameter.

In panel a in Fig. 3, we plot the mean proportions of FTV responses across observers for the whole figures, upper parts, and lower parts as a function of figure gender. In panels b, c, and d in Fig. 3, we plot the mean and 95%

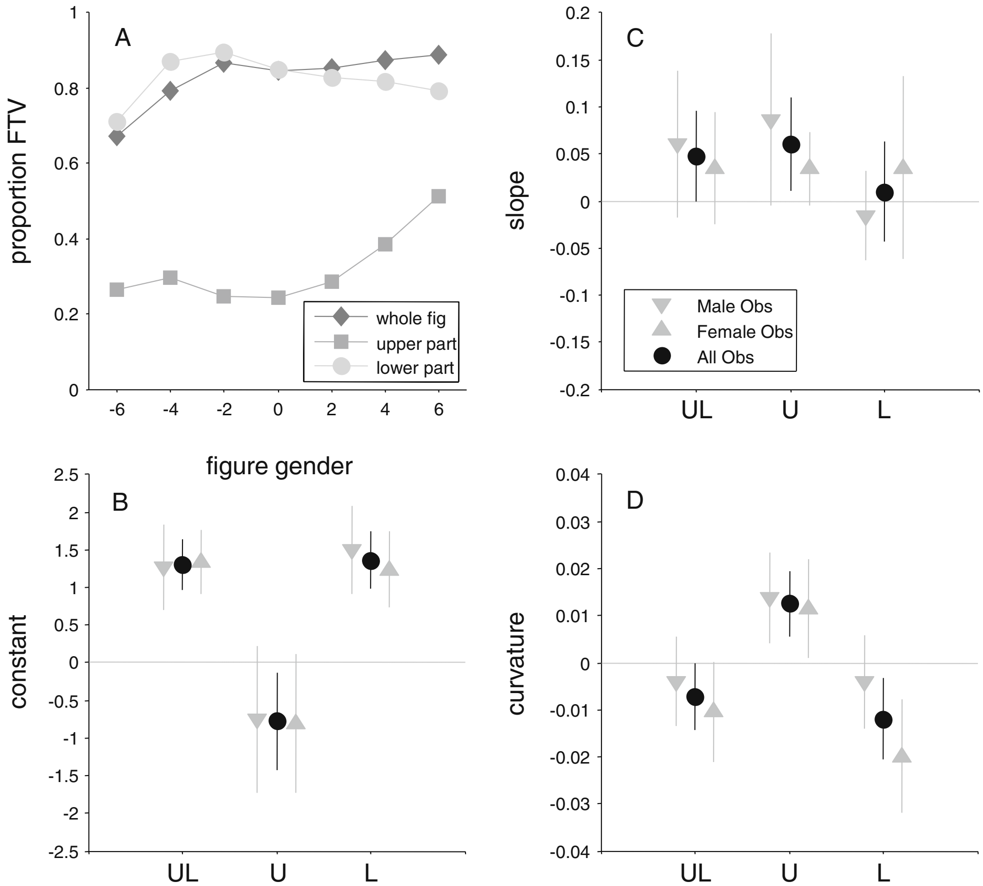

Fig. 3 Data for Experiment 2 for whole figures (UL), upper-part-only figures (U), and lower-part-only figures (L). **a** Mean proportions (across all observers) of facing-the-viewer (FTV) responses as a function of figure gender. **b**–**d** Mean parameter values of the second-order polynomial fit on the probit-transformed FTV responses as a function of figure gender. Black circles represent means and 95% confidence intervals across all observers. Gray arrows pointing downward/upward represent the data for male and female observers, respectively

confidence intervals across observers and across male and female observers separately, for each of the three parameters in each condition. The crucial question concerned the dependency of the facing bias on figure part. From panel a in Fig. 3, it is clear that there is a strong effect of figure part on the overall proportions of FTV responses and, thus, also on the constant parameter (see panel b). Consistent with previous findings (Brooks et al., 2008; Schouten et al., 2010; Vanrie et al., 2004), a strong facing bias in the whole-figure condition was observed (82.81% FTV responses; mean z value significantly positive), $t(13) = 7.48$, $p < .001$. A similar facing bias was found for the lower-part-only condition (82.40% FTV responses; mean z value significantly positive), $t(13) = 7.07$, $p < .001$. In the upper-part-only condition, however, no facing bias is apparent. Instead, observers appeared to perceive the figure as facing away (31.89% FTV responses; mean z value significantly negative), $t(13) = -2.37$, $p = .03$. Paired t tests showed that the mean constant parameters for upper-part-only figures and lower-part-only figures strongly differed, $t(13) = -5.79$, $p < .001$, as did the mean constant parameters of the upper-part-only and whole figures, $t(13)- = -7.10$, $p < .001$. The mean constant parameter for the lower-part-only and whole figures did not differ, $t(13) = 0.28$, $p = .79$. These results suggest that information in the lower part of the figure is responsible for the facing bias.

From panels a and c in Fig. 3, no strong differences between the slopes are apparent. A one-way repeated measurement ANOVA on the slope values revealed no effect of figure part, $F(2, 26) = 1.31$, $p = .29$. However, on the basis of previous research (Brooks et al., 2008; Schouten et al., 2010), a positive figure gender effect and, thus, a positive slope was expected in the whole-figure condition. Here, in the whole-figure condition, the mean slope was found to be significant at the .05 level in a one-tailed t test, $t(13) = 1.95$, $p = .04$; not significant in a two-tailed t test. The mean slope for the upper-part-only condition for which we had no a priori expectations was also found to be significantly positive (two-tailed t test; $t(13) = 2.37$, $p = .04$). The mean slope in the lower-part-only condition did not differ from zero, $t(13) = 0.36$, $p = .73$.

Panels a and d in Fig. 3 suggest a strong effect of figure part on the curvature parameter. This is confirmed by a significant effect of figure part in a one-way repeated measurement ANOVA on the curvature values of the three part conditions, $F(2, 26) = 19.78$, $p < .001$. In the whole-figure condition, t tests revealed that there was a tendency toward a negative curvature, $t(13) = -2.01$; $p = .07$, and there was a significant negative curvature in the lower-part-only condition, $t(13) = -2.73$; $p = .02$. The curvature in the upper-part-only condition was significantly positive, $t(13) = 3.57$; $p = .003$.

To test for observer sex effects we performed a 3 × 2 repeated measurement mixed ANOVA (figure part condition as a within-subjects variable and observer sex as a between-subjects variable) on the values of each of the three parameters. These analyses revealed no main effects of observer sex and no interactions of figure part and observer sex.

Discussion

The results of Experiment 2 confirm what was reported by some participants in our previous experiment. When presented in isolation, the lower part of the point-light walker elicited a strong facing bias. The upper part, in contrast, seems, on average, to have been perceived as FA. The facing bias that was observed for the whole point-light walkers is quite similar to the facing bias for the lower parts. This suggest that the facing bias arises from stimulus properties in the lower part of the point-light walker. To establish and further explore the effects reported in Experiments 1 and 2, we designed a third experiment.

Experiment 3

Introduction

The first goal of Experiment 3 was to test the robustness of the effects found in Experiments 1 and 2. On the one hand, our aim was to replicate the positive relation between figure gender and facing bias for structure-only stimuli and the negative relation between figure gender and facing bias for kinematics-only stimuli. On the other hand, we intended to replicate the finding that whole figures and their lower parts elicit a strong facing bias and that the upper parts are, on average, perceived as facing away.

The second goal of Experiment 3 was to explore a potential interaction between the variables that were manipulated in Experiments 1 and 2. It could be possible, for instance, that the structural or kinematic differences that induce changes in the perceived in-depth orientation affect the perceived in-depth orientation only of the upper or lower part of the figure. As such, the presence of an interaction between gender cue and figure part could provide more detailed information on the particular stimulus properties playing a role in the perceived in-depth orientation of point-light figures.

Therefore, in the present experiment, we manipulated within subjects the gender of the point-light figure (seven levels: from extremely female to extremely male), as well as the gender cue (three levels: original, structure-only, or kinematics-only point-light figures) and the figure part (three levels: the whole point-light figure or only the upper or lower part). Observer sex was the between-subjects variable. FTV responses for all the stimulus combinations were recorded.

Method

Participants Twenty-two paid observers (11 males and 11 females) participated. All the observers had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment. None of them had participated in previous experiments investigating the facing bias.

Stimuli and apparatus All the stimuli were derived from a combination of the stimulus manipulations that were described in the Method sections of Experiments 1 and 2. The combination of manipulations led to the following nine sets of seven point-light stimuli: SKUL, SUL, KUL, SKU, SU, KU, SKL, SL, and KL, where S and/or K stand for the presence of structural and/or kinematic differences, respectively, between the figures and U and/or L stand for the presence of the upper and/or lower parts, respectively, of the point-light figures.

Procedure Procedural details that differ from those in Experiments 1 or 2 were the following. All variables (except for observer sex) were manipulated within subjects. Trials were randomized and divided into 21 sessions of 24 trials. Between sessions, participants could take a break. Each participant completed 504 trials (63 stimuli * 8 repetitions), which lasted about an hour.

Results

As in Experiments 1 and 2, for each observer for each of the conditions, the probit-transformed proportions of FTV responses as a function of figure gender were fitted with a second-order polynomial, returning a constant, slope, and curvature parameter. In Fig. 4, we plot the mean proportions of FTV responses across all observers as a function of figure gender (panels a–c) and the means and 95% confidence intervals across observers and across male and female observers separately for each of the three parameters in each condition. Data for point-light figures varying only in structural, kinematic, and both structural and kinematic information are vertically aligned in the left, middle, and right columns, respectively. For each parameter separately, a 3 (gender cue: SK, S, K) × 3 (figure part: UL, U, L) repeated measurement ANOVA was performed. Other ANOVAs and t tests will be mentioned separately.

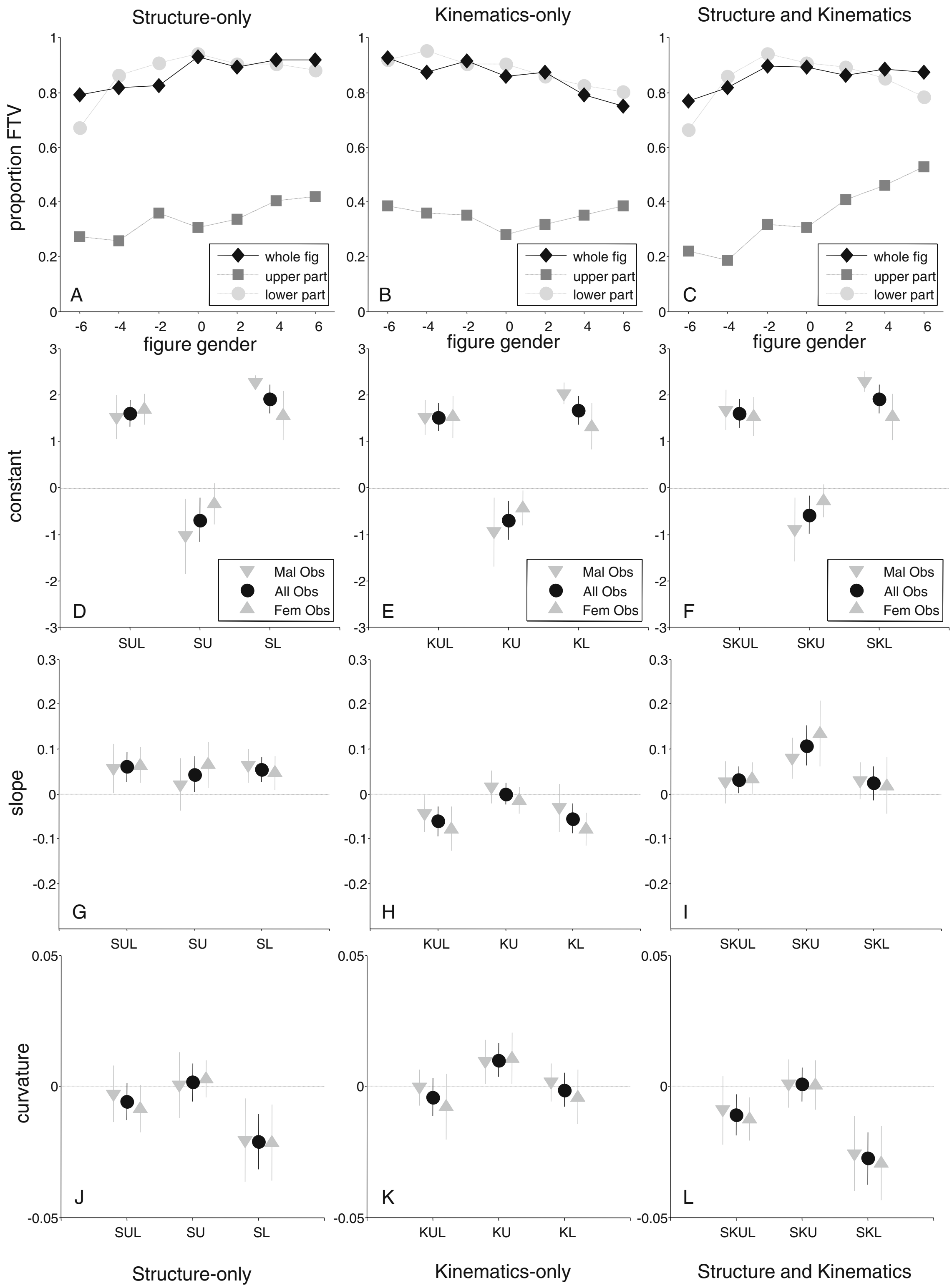

Fig. 4 Data for Experiment 3. **a**–**c** Mean proportions (across all observers) of facing-the-viewer (FTV) responses as a function of figure gender. d–l Mean parameter values of the second-order polynomial fit on the probit-transformed FTV responses as a function of figure gender for each of the conditions. Black circles represent means and 95% confidence intervals across all observers. Gray arrows pointing downward/upward represent the data for male and female observers, respectively

First, we checked whether we replicated the findings of Experiments 1 and 2. In panels a, b, g, and h in Fig. 4, we can see that, as was observed in Experiment 1, the slopes of the number of FTV responses as a function of figure gender for structure-only (SUL) and kinematics-only (KUL) figures strongly differ. This is confirmed by a significant main effect of gender cue for the slope parameter, $F(2, 168) = 28.33$, $p < .001$. Whole structure-only figures (SUL) elicit a positive slope, $t(21) = 3.39$, $p = .003$), whereas whole kinematics-only figures (KUL) elicit a negative slope, $t(21) = -3.61$, $p = .002$.

As was the case in Experiment 2, panels d, e, and f in Fig. 4 suggest a strong effect of figure part for the constant parameter. This is confirmed by a strong main effect of figure part in the repeated measurement ANOVA on the constant parameters, $F(2, 168) = 199.31$, $p < .001$. The original point-light figures (SKUL; 85.71% FTV responses; mean z value significantly positive), $t(21) = 10.04$, $p < .001$, and their lower-part-only versions (SKL; 84.33% FTV responses; mean z value significantly positive), $t(21) = 11.66$, $p < .001$, elicit a strong facing bias. The upper-part-only versions (SKU; 34.74% FTV responses; mean z values significantly negative), $t(21) = -2.73$, $p = .01$, are, on average, again perceived as facing away. As was observed in Experiment 2, curvature for the lower-part-only figures generally seems to differ from curvature for the upper-part-only figures. This is reflected in a significant main effect of the curvature parameter for figure part, $F(2, 168) = 22.61$, $p < .001$. In general, the present results thus confirm the basic findings of Experiments 1 and 2.

Second, we explored the interaction between gender cue and figure part for the constant, slope, and curvature parameters. For the constant parameter, we found no significant interaction between gender cue and figure part, $F(4, 168) = 0.14$, $p = .97$. For the slope parameter, however, we observed a significant interaction, $F(4, 168) = 2.81$, $p = .027$. An inspection of panel g in Fig. 4 suggests that the positive figure gender effect that is found for whole structure-only figures (SUL) is present in the upper part (SU), as well as in the lower part (SL), of the figure. As was confirmed by a one way repeated measurements ANOVA on figure part for the structure-only stimuli, the slopes of the whole structure-only (SUL), structure–upper-part-only (SU) and structure–lower-part-only (SL) figures do not differ, $F(2, 42) = 0.31$, $p = .73$. A closer look at the slopes for the kinematics-only figures in panel h of Fig. 4 suggests that kinematics–upper-part-only figures (KU) do not show a figure gender effect, whereas kinematics–lower-part-only figures (KL) show the same negative figure gender effect as that observed for the whole kinematics-only figures (KUL). Paired t tests on the slopes of the three figure part conditions for the kinematics-only stimuli showed that the slope for kinematics–upper-part-only figures differed significantly from the slope for whole kinematics-only figures, $t(21) = 2.97$, $p = .007$, as well as from the slope for kinematics–lower-part-only figures, $t(21) = 2.83$, $p = .01$. The slope of whole kinematics-only figures and kinematics–lower-part-only figures, however, did not differ, $t(21) = -0.30$, $p = .77$. This suggests that the negative relation between perceived in-depth orientation and figure gender that is found for the kinematics gender cue acts mainly in the lower part of the figure. For completeness, we mention the marginally significant interaction between gender cue and figure part for the curvature parameter, $F(4, 168) = 2.39$, $p = .05$. Taken together, the present data thus reveal an interaction between gender cue and figure part.

At first sight, from panels d–l in Fig. 4, no systematic parameter differences between male and female observers are apparent. However, a closer inspection of panels d–f in Fig. 4 suggests a difference for the constant parameter. For upper-part-only stimuli (SKU, SU, and KU), on average, male observers seem to show smaller constant values, when compared with female observers. For lower-part-only stimuli (SKL, SL, and KL), in contrast, the reverse appears to be true: Male observers systematically show higher constant values, as compared with female observers. These observations are confirmed by a 2 (upper part vs. lower part) × 2 (male vs. female observers) ANOVA on the constant parameter. While there was no main effect of observer gender, $F(1, 20) = 0.06$, $p = .81$, we found, on top of the strong effect of figure part, $F(1, 20) = 93.40$, $p < .001$, a significant interaction between figure part and observer sex, $F(1,20) = 7.04$, $p = .02$.

Discussion

First, consistent with what was observed in Experiment 1, we found structure-only point-light figures to elicit a positive and kinematics-only figures to elicit a negative relation between figure gender and facing bias. Moreover, as was found in Experiment 2, in Experiment 3 whole figures and lower-part-only figures evoked a strong facing bias, and upper-part-only stimuli, on average, evoked the tendency to perceive the point-light figure as facing away. We can thus conclude that the gender cue effect, observed in Experiment 1, and the figure part effect, observed in Experiment 2, were reliably replicated in Experiment 3.

Second, the results of Experiment 3 indicated that the gender cue effect (slope) depends on the part of the figure that is available. More specifically, the data indicated that the negative relation between figure gender and the facing bias that is observed for whole kinematics-only point-light figures mainly results from information in the lower part. We also found a marginally significant interaction for the curvature parameter. Overall, the interaction between the gender cue effect and the figure part effect indicates that stimulus properties affect the perceived in-depth orientation differently in different parts of the figure.

Third, responses to stimuli that contain both structural and kinematic gender cues seem to resemble the responses to the structure-only stimuli more than the responses to the kinematic-only stimuli. This suggests that observers seem to rely more on the structural cues than on the kinematic cues when both are available.

Also worthy to note is that in Experiment 3, again, significant differences in the FTV responses of male and female observers were found. Male observers showed a stronger facing bias for whole and lower-part-only figures. but they also showed a stronger tendency to perceive the upper-part-only figure as facing away. It remains unclear, however, what exactly causes this difference in response pattern between male and female observers.

General discussion

To test whether behavioral or social relevance causes the facing bias for depth-ambiguous point-light walkers, Brooks et al. (2008) explored whether the gender of the point-light figure had an effect on the facing bias. A strong effect of figure gender on the facing bias was observed: The facing bias was found only for male and gender neutral point-light figures. Extreme female figures were perceived as facing away. In addition to a (weaker) figure gender effect, Schouten et al. (2010) found an observer sex effect: The facing bias for male point-light walkers was stronger for male observers than for female observers. While these observations are consistent with the account assuming that the perceived gender biases the perceived in-depth orientation of a point-light walker, they do not provide conclusive evidence. Indeed, crucial for the validity of such an account is the demonstration of a causal link between perceived gender and perceived in-depth orientation. The goal of the present study was to test whether or not this relation is causal.

The present study provided the following findings. First, the results of Experiment 1 demonstrated that the relation between perceived gender and perceived in-depth orientation is not causal. Structural and kinematic stimulus changes that induced comparable changes in perceived gender were found to elicit opposite changes in perceived in-depth orientation. While we observed a positive relation between figure gender and facing bias for structure-only stimuli, the sign of the relation was inverted for kinematics-only stimuli. From this, we can conclude that stimulus properties, irrespective of the perceived gender they elicit, play a crucial role in biasing the in-depth perception of depth-ambiguous point-light walkers. Second, the results of Experiment 2 indicated that the facing bias arises from information in the lower part of the point-light figure. Moreover, the data showed that the perceived in-depth orientation of whole figures is highly comparable to the perceived in-depth orientation of lower-part-only stimuli but is quite different from the perceived in-depth orientation of upper-part-only stimuli. This suggests that, to judge the in-depth orientation, observers preferably rely on the lower part of the point-light figure. Third, in Experiment 3, an interaction between the effects reported in Experiments 1 and 2 was demonstrated. This interaction was observed for the parameters that express the relation between perceived in-depth orientation and figure gender (significant for the slope and marginally significant for the curvature), suggesting that structural and/or kinematic properties differentially affect the upper and lower parts of the stimulus. For example, the negative relation between figure gender and facing bias that was observed for kinematic-only whole figures was also found for the kinematic-only lower parts, but not for the kinematic-only upper parts.

Obviously, several questions remain. First, the results of the present study do not yet provide a clear insight into the causes of the facing bias. Our findings point to an important role for structural and kinematic information in the lower part of the point-light walker. When presented in isolation, kinematic properties in the lower part of the female figures seem to elicit a strong facing bias. Kinematic properties in the lower part of male figures also elicit a facing bias, but much weaker. Structural properties in the lower part of gender-neutral figures give rise to a strong facing bias, but the more male or female the figure is, the weaker the facing bias is. The drop in facing bias is strongest on the female side of the continuum. More experiments are necessary to find out in detail which stimulus properties elicit the facing bias, but it nevertheless might be interesting to speculate. Recent studies (Chang & Troje, 2008, 2009a, 2009b; Saunders, Suchan, & Troje, 2009; Troje & Westhoff, 2006) showed that the local inversion effect in biological motion perception is carried by the dots representing the feet. Observers are able to correctly judge the left–right direction of a sagittal scrambled point-light figure. However, when the scrambled point-light display or only the trajectories of the foot dots are inverted, this ability disappears. These studies suggested the existence of a *life detector*, a visual filter that is tuned to quickly and automatically detect the presence of a moving living organism and direct attention to it. The mechanism is found to be specifically sensitive to the gravitational forces on the legs and to acceleration in the motion. The filter is believed to be evolutionarily old and innate, and its main function would be to alert the observer to a potentially dangerous or otherwise demanding situation (Troje & Chang, in press). Because of the apparent similarities between the type of information that is necessary to elicit the facing bias and to trigger the life detector–namely, the presence of particular kinematic information in the feet–here, we speculate that the facing bias might be somehow related to the life detector mechanism. For example, the vertical accelerations in trajectories of the feet that signal the potential presence of a moving organism might also trigger the perceptual system's tendency to err on the side of caution. Such a mechanism could provide a considerable evolutionary benefit, especially in situations in which the direction of motion of the feet is ambiguous. One interesting direction for future research on the in-depth perception of point-light walkers could thus be to investigate in detail the role of accelerations in the foot dots.

Second, it remains unclear why upper-part-only stimuli elicit a bias to perceive the figure as facing away. The positive relation between figure gender and facing bias for structure-only upper parts (Fig. 4a, g) suggests that the perceived in-depth orientation of the upper part depends on the spatial relations between the dots. The presence of kinematic gender variations on top of structural variations (Fig. 4c, i) in the upper parts seems to amplify this positive relation. Note that while across one step cycle, the structure of kinematics-only gender figures remains constant, at comparable points within one step cycle, the structure of the kinematic-only figures can differ. As such, kinematic properties could amplify particular structural configurations when the gender figures vary in both structure and kinematics. For upper-part figures that vary in both structure and kinematics, the bias to perceive the stimulus as facing away is strongest for upper parts of female figures but is almost absent for upper parts of extreme male figures.

At first sight, the present results seem to be at odds with the results of Vanrie and Verfaillie (2006), who suggested that the upper limbs play the primary role in eliciting the facing bias. However, the point-light stimuli for which Vanrie and Verfaillie (2006) observed the facing bias, likely to be caused by information in the upper part, were quite different from the stimuli used in the present experiment. In their Experiment 3, Vanrie and Verfaillie (2006) explored the role of the direction of movement of the upper and lower limbs. Movement directions were either lateral or perpendicular to the plane of the torso. Observers had to judge the in-depth orientation of four semantically meaningless point-light stimuli. The point-light figures were either making a lateral or a perpendicular sway with the upper limbs or making a lateral or a perpendicular step with the lower limbs. The stimuli were presented in a frontal view and a three-quarters view (rotation of 45°). The results of this experiment showed that the direction of movement of the lower limbs had no effect on the proportions of FTV responses. The direction of movement of the upper limbs, however, had a strong effect. Point-light figures featuring a perpendicular arm sway elicited a strong facing bias, whereas figures featuring a lateral arm sway did not. A crucial aspect of the results of Vanrie and Verfaillie (2006) that should be mentioned here is that the upper limb effect was observed only for the point-light figures in a three-quarters view. One explanation put forward by the authors assumed that the facing bias arises for the upper part because the arms may function as a figure on the background of the torso. This line of reasoning by Vanrie and Verfaillie (2006) not only might provide an explanation of their results, but also might explain the difference between their results that the upper part seemed to elicit the facing bias and the present finding that the upper part of a point-light walker elicits mainly *facing-away* interpretations. When the wrist dots move within the area delineated by dots making up the torso (shoulder and hip dots), some form of local, motion-induced figure–ground segregation may take place. This happens for the three-quarters view figures of Vanrie and Verfaillie (2006) in which the upper limbs move perpendicularly. However, this does not occur in the frontal view stimuli of Vanrie and Verfaillie (2006) or in any of their other stimuli in which the upper limbs swing laterally. Similarly, in the point-light walkers used in the present study, the wrist dots never entered the region of the torso. In contrast, in our stimuli, the elbow dots, especially for female figures, did enter the region of the torso. Contrary to the wrists, the elbows in a figure featuring a female structure tend to move *behind* the torso, instead of in front of the torso, and therefore lead to *occlusion violations* (see Vanrie & Verfaillie, 2006). That is, if the figure was to be oriented toward the viewer, the elbow dots should, in principle, be occluded. In our stimuli, the elbow dots were actually never occluded, potentially triggering the facing away interpretation for figures in which the elbow dots entered the region of the torso. This might also explain the positive relation between figure gender and perceived in-depth orientation that we observed for the upper part stimuli. The more male the figures are, the more the elbows point outward. For extreme male figures, the elbow dots never enter the region that is normally occupied by the torso.

Together, the present results and those of Vanrie and Verfaillie (2006) thus suggest that the perceived in-depth orientation of a point-light figure, or even a part of a point-light figure, strongly depends on its spatiotemporal characteristics. This means that findings on the perceived in-depth orientation of a particular point-light action cannot be generalized to other point-light actions.

Third, as was revealed by the results of Experiment 3, there is also a positive figure gender effect for structure-only lower parts. This suggests, on top of the importance of the spatial relations between the dots of the upper part, as discussed above, an important role for the spatial relations between the dots of the lower part. Inspection of the structural properties in the lower part that vary as the figures change along the gender dimension does not, however, suggest a comparable explanation as for the upper part.

Instead, we speculate that the effect of structural information in the lower part might also be related to the life detector mechanism. The results of Chang and Troje (2009a) suggested that for retrieving the direction from scrambled biological motion displays, the processing of the local spatiotemporal cues inherent to the isolated motion of one foot are not sufficient. Critically, for the life detector to be activated, the foot's elemental cues must be evaluated with reference to the motions of other elements, or at least to other parts of the same element's trajectory. Hence, if the facing bias were to be driven by kinematic properties in the feet of the point-light walker, the reference that one foot dot constitutes for the other might be crucial. The more female/male the point-light figure is, the smaller/larger is the distance between the dots of the feet. Notably, the closer to the female extreme of the gender continuum the figure is (−2, −4, −6 *SD*), the more progressively the dots of the feet overlap, thereby potentially disrupting the reference that is crucial to triggering the life detector. The strongest facing bias is observed for neutral figures (0 *SD*), whereas, when the figure enters more into the male side of the gender continuum (2, 4, 6 *SD*), a saturation or even a small decrease in the strong facing bias for structure-only lower parts can be observed (Fig. 4a), leading to a negative curvature (Fig. 4j). This might reflect the fact that neutral lower parts (0 *SD*) carry, among all gender figures, the optimal distance between the feet dots for the reference and that when the distance between the feet dots grows too big, the reference gradually gets disrupted. These hypotheses should, of course, also be tested in future research. This could be done, for example, by explicitly manipulating, for one foot dot, the presence of and relative distances to particular reference points.

Fourth, in Experiments 1 and 3, we showed that structural and kinematic differences between point-light figures have a strong effect on the perceived in-depth orientation. The data of Experiment 3 seem to suggest that, to judge the perceived in-depth orientation, observers rely more on the structural cues than on the kinematic cues. Neurophysiologically plausible models on the perception of biological motion (e.g., Giese & Poggio, 2003) generally incorporate two pathways, a form pathway and a motion pathway, that process the structural and kinematic properties of biological motion in a relatively independent manner before converging into common areas such as the superior temporal sulcus (STS), premotor cortex, and fusiform and occipital face area (see also Jackson & Blake, 2010). Recently, Vangeneugden, Pollick, and Vogels (2009) reported evidence for the existence of "snapshot" neurons, which code for form/posture, in the lower bank and "motion" neurons, which code for visual kinematics, in the upper bank/fundus of the macaque STS. Future neurophysiological and behavioral research should investigate whether the dependency of the perceived in-depth orientation on the manipulation of structural and kinematic components in biological motion figures reflects the selective invasion of these specifically tuned neural structures.

Fifth, observer sex effects are repeatedly observed. However, the way in which they show up seems rather inconsistent. In Schouten et al. (2010), male observers showed a stronger facing bias than did female observers for male, but not for female, point-light figures. In Experiment 1 of the present study, male observers generally showed a somewhat stronger facing bias than did female observers. In Experiment 3, male observers showed a stronger facing bias than did female observers for whole and lower-part-only figures, but for upper-part-only figures, male observers more strongly perceived the figure as facing away. Possibly due to the smaller sample size (7 females, 7 males) in Experiment 2, no observer sex effects were observed. Given the strong effects of figure part and gender cue, a possible explanation of observer sex effects could be that male observers attend to different stimulus parts or different stimulus properties than do female observers (Hewig, Trippe, Hecht, Straube, & Miltner, 2008; Johnson & Tassinary, 2005). Why the effects are not always observed in a consistent form remains unclear.

In summary, the present study provided two key findings concerning possible causes of the facing bias. First, we showed that the link between perceived gender and perceived in-depth orientation is not causal. Second, we demonstrated that the facing bias is entirely carried by information in the lower part of the point-light walker. Thus, our data do not support accounts assuming that the facing bias is driven by the potential behavioral or social relevance inferred from the global percept of a human figure. They are, however, consistent with more locally acting stimulus properties affecting the perceived in-depth orientation of parts of the point-light walker. Yet, which particular stimulus properties consistently bias the perceptual in-depth organization and whether these biases reflect innate mechanisms or learned priors remain unclear. Experimentally testing the hypotheses brought forward in this article could be the next step forward.

Acknowledgements This research was supported by the Scientific Research Fund–Flanders, FWO G.0621.07 to K.V., and by grants from NSERC and CIFAR to N.F.T. We also thank Ilse Van Dromme for assistance in data collection.

References

Barclay, C. D., Cutting, J. E., & Kozlowski, L. T. (1978). Temporal and spatial factors in gait perception that influence gender recognition. *Perception & Psychophysics, 23*, 145–152.

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

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*, R728–R729. doi:10.1016/j.cub.2008.06.054

Chang, D. H. F., & Troje, N. F. (2008). Perception of animacy and direction from local biological motion signals. *Journal of Vision, 8*(5, Art. 10). doi:10.1167/8.5.3

Chang, D. H. F., & Troje, N. F. (2009a). Acceleration carries the local inversion effect in biological motion perception. *Journal of Vision, 9*(1, Art. 17). doi:10.1167/9.1.19

Chang, D. H. F., & Troje, N. F. (2009b). Characterizing global and local mechanisms in biological motion perception. *Journal of Vision, 9*(5, Art. 10). doi:10.1167/9.5.8

Cutting, J. E. (1978). Generation of synthetic male and female walkers through manipulation of a biomechanical invariant. *Perception, 7*, 393–405. doi:10.1068/p070393

Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in Cognitive Sciences, 8*, 396–403. doi:10.1016/j.tics.2004.07.002

Giese, M. A., & Poggio, T. (2003). Neural mechanisms for the recognition of biological movements. *Nature Reviews. Neuroscience, 4*, 179–192. doi:10.1038/nrn1057

Hewig, J., Trippe, R. H., Hecht, H., Straube, T., & Miltner, W. H. R. (2008). Gender differences for specific body regions when looking at men and women. *Journal of Nonverbal Behavior, 32*, 67–78. doi:10.1007/s10919-007-0043-5

Hiris, E., & Ewing, K. (2010). The perceived sex of biological motion displays is influenced by adaptation to biological motion but not adaptation to static faces. *Journal of Vision, 10*(7), 781. doi:10.1167/10.7.781 Abstract.

Jackson, S., & Blake, R. (2010). Neural integration of information specifying form, motion, and depth. *The Journal of Neuroscience, 20*, 838–848. doi:10.1523/jneurosci.3116-09.2010

Jackson, S., Cummins, F., & Brady, N. (2008). Rapid perceptual switching of a reversible biological figure. *PLoS ONE, 3*, e3982. doi:10.1371/journal.pone.0003982

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception & Psychophysics, 14*, 201–211.

Johnson, K. L., & Tassinary, L. G. (2005). Perceiving sex directly and indirectly: Meaning in motion and morphology. *Psychological Science, 16*, 890–897. doi:10.1111/j.1467-9280.2005.01633.x

Jordan, H., Fallah, M., & Stoner, G. R. (2006). Adaptation of gender derived from biological motion. *Nature Neuroscience, 9*, 738–739. doi:10.1038/nn1710

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

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

Pollick, F. E., Kay, J. W., Heim, K., & Stringer, R. (2005). Gender recognition from point-light walkers. *Journal of Experimental Psychologyz: Human Perception and Performance, 31*, 1247–1265. doi:10.1037/0096-1523.31.6.1247

Saunders, D. R., Suchan, J., & Troje, N. F. (2009). Off on the wrong foot: Local features in biological motion. *Perception, 38*, 522–532. doi:10.1068/p6140

Schouten, B., & Verfaillie, K. (2010). Determining the point of subjective ambiguity of ambiguous biological motion figures with perspective cues. *Behavior Research Methods, 42*, 161–167. doi:10.3758/BRM.42.1.161

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, & Psychophysics, 72*, 1256–1260.

Troje, N. F. (2002). Decomposing biological motion: A framework for analyses and synthesis of human gait patterns. *Journal of Vision, 2*, 371–387. doi:10.1167/2.5.2

Troje, N. F. (2008). Retrieving information from human movement patterns. In T. F. Shipley & J. M. Zacks (Eds.), *Understanding events: How humans see, represent, and act on events*. Oxford: Oxford University Press.

Troje, N. F., & Chang, D. H. F. (in press). Shape-invariant processing of biological motion. In K. Johnson & M. Shiffrar (Eds.), *Visual perception of the human body in motion: Findings, theory, and practice* (pp. 308-335). Oxford: Oxford University Press.

Troje, N. F., & Szabo, S. (2006). *Why is the average walker male?* Sarasota, FL: Poster presented at the Vision Science Society meeting.

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.

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), 850–857. doi:10.1167/6.8.7

van der Zwan, R., Machatch, C., Kozlowski, D., Troje, N. F., Blanke, O., & Brooks, A. (2009). Gender bending: Auditory cues affect visual judgements of gender in biological motion displays. *Experimental Brain Research, 198*, 373–382. doi:10.1007/s00221-009-1800-y

Vangeneugden, J., Pollick, F., & Vogels, R. (2009). Functional differentiation of macaque visual temporal cortical neurons using a parametric action space. *Cerebral Cortex, 19*, 593–611. doi:10.1093/cercor/bhn109

Vanrie, J., & Verfaillie, K. (2006). Perceiving depth in point-light actions. *Perception & Psychophysics, 68*, 601–612.

Vanrie, J., & Verfaillie, K. (2008). Perceptual coupling of multiple point-light figures. *Visual Cognition, 16*, 585–615. doi:10.1080/13506280701269334

Vanrie, J. & Verfaillie, K. (2010). *On the reversibility of point-light actions*. Manuscript submitted for publication.

Vanrie, J., Dekeyser, M., & Verfaillie, K. (2004). Bistability and biasing effects in the perception of ambiguous point-light walkers. *Perception, 33*, 547–560. doi:10.1068/p5004

Verfaillie, K. (2000). Perceiving human locomotion: Priming effects in direction discrimination. *Brain and Cognition, 44*, 192–213. doi:10.1006/brcg.2000.1228

Wichmann, F. A., & Hill, N. J. (2001a). The psychometric function: I. Fitting, sampling, and goodness of Fit. *Perception & Psychophysics, 63*, 1293–1313.

Wichmann, F. A., & Hill, N. J. (2001b). The psychometric function: II. *Bootstrap-based confidence intervals and sampling. Perception & Psychophysics, 63*, 1314–1329.