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Gender discrimination in biological motion displays based on dynamic cues

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SUMMARY

Studies of human locomotion have found that male and female walkers differ in terms of lateral body sway, with males tending to swing their shoulders from side to side more than their hips, and females tending to swing their hips more than their shoulders. Experiments reported here demonstrate that naive viewers can identify the gender of the figure in a biological motion display very reliably when the display contains gender-specific lateral body sway. Sensitivity to gender is high even for displays containing only a fraction of a step cycle. This dynamic cue dominates structural cues based on torso shape ('centre-of-moment') when the cues are set in opposition. It is mediated by gender-specific differences in the velocity of shoulder and hip dots, not by positional differences in shoulder and hip dots during the step cycle.

1. INTRODUCTION

The earliest modern demonstrations of perception of biological motion were reported by Johansson (1973). He attached small light sources at the major joints of human actors, and filmed them moving about in darkness. When the film was played to naive observers they immediately interpreted the moving pattern of isolated points as a human figure. On the basis of a series of papers published by Cutting and co-workers in the late 1970s, it is now widely accepted that observers can correctly identify the gender of the walking figure in biological motion displays. Cutting concluded that this ability is based on cues about torso shape conveyed by dots placed on the shoulders and hips. Men have wider shoulders relative to their hips than women, and he argued that information about the ratio of shoulder width to hip width was available in biological motion displays. Cutting *et al.* (1978) correlated the width ratio of the actors they filmed with their gender discriminability, and obtained a correlation coefficient of 0.84. They described the putative gender cue as the 'centre-of-moment', and discussed other possible ways of measuring it (e.g. drawing diagonals across the torso), but fundamentally the cue depends on torso structure.

In Kozlowski & Cutting's (1977) initial study, gender discrimination performance was far from perfect, at 63% correct on average. A year later, Barclay *et al.* (1978) varied exposure duration and obtained discrimination levels of 45%, 46%, 52% and 66% for durations of 0.4 s, 0.8 s, 1.6 s and 4.4 s, respectively. Why was performance so low? Both studies used sagittal (side) views of walking figures, so direct information about width ratio was obscured. However, during the step cycle the shoulders and hips twist in opposite directions about the vertical axis.

Barclay *et al.* (1978) suggested that dots on broader male shoulders might move back and forth in a side view over a greater distance than dots on narrower female shoulders (vice versa for hips), owing to the gender difference in torso structure. This would occur even if the angle of torso twist was equal for males and females (no claims were made about the equality or inequality of torso twist between the sexes, nor were any measurements taken from their walkers).

If gender discrimination really is mediated by cues about torso structure, then oblique or frontal views ought to be much more effective than side views. We conducted an experiment to measure gender discrimination as a function of view angle. Biological motion displays were synthesized by using the method originally described in Cutting (1978), to allow us complete control over gender cues offered by the displays (males and females differ in terms of cadence, stride length, arm swing etc., none of which could be controlled in Cutting *et al.*'s films). However, that algorithm was designed for side views only, and made no provision for lateral (*z*-axis) excursions of body points which are obscured in such views. We therefore had to develop the algorithm to include lateral sway. Very few studies compare sideways body movements during locomotion in males and females (nearly all studies of 'human' movement are based on male subjects). One such study, by Murray *et al.* (1970), notes that:

Which part of the body shifts laterally appears to be an optional and attitudinal characteristic of gait. It appears to be a masculine attitude to show greater lateral shifting of the head and thorax, and less lateral shifting of the pelvis. Conversely, the feminine attitude appears to be characterised by less lateral shifting of the head and thorax, but greater lateral shifting of the pelvis.

Accordingly, the 'walker' algorithm was developed to

allow sideways movement of the upper and lower body, based on previous data (Murray *et al.* 1964, 1970; Murray 1967). Clearly, in oblique or frontal views, dynamic information about lateral body sway is gender specific, and could offer a cue for discrimination that is entirely independent of the structural cue proposed by Cutting and co-workers. We decided to pit the structural and dynamic cues against each other. Synthetic walkers were created that had either male or female torso structure, each with either male or female body sway. Are gender judgements dominated by the structural cue or by the dynamic cue?

2. EXPERIMENT 1. PHYSIQUE AND LATERAL MOVEMENT CUES IN GENDER RECOGNITION

(a) Method

(i) *Subjects.* Four female and four male observers participated in the experiment. All had some experience of biological motion displays, although none had been required to make gender judgements.

(ii) *Stimuli.* A PC-compatible computer with a high-performance raster graphics system displayed stimuli on a NEC Multisync plus colour monitor (640 × 480 pixel resolution, 60 Hz refresh rate). Human figures were defined by 13 single-pixel light points, located on the head, both shoulders, elbows, wrists, hips, knees and ankles. None of the light points were occluded by other subjective parts of the figure. Animated sequences were generated by calculating the three-dimensional trajectory of each light point over a single walking step cycle, and temporally sampling the coordinates to produce 40 static frames. The x and z coordinates of each frame (x_1 and z_1) were then transformed to simulate a transverse (y -axis) rotation of the figure through angle ϕ :

$$x_2 = x_1 \cos \phi + z_1 \sin \phi,$$

$$z_2 = z_1 \cos \phi - x_1 \sin \phi,$$

where x_2 and z_2 represent transformed x and z coordinates; y coordinates, corresponding to the axis of rotation, remaining unchanged. Three-dimensional x - y - z coordinates were converted into two-dimensional x - y screen coordinates by using parallel projection. When the sequence of static frames was shown in rapid succession, a vivid impression of a walking person emerged. There was no progressive component to the walking motion, so the figure walked as if on an unseen treadmill, oriented at a given angle towards or away from the observer. The synthetic figures varied in both their torso structure and lateral sway.

Torso structure refers to the relative width of the shoulders and hips. Shoulder and hip widths were based on data collected from 20 females and 20 males at Sussex University, aged 19–35 years old. Widths represented the greatest lateral extent of the joints in the frontal plane, including the greater tuberosity of the humerus at the shoulders, and the greater trochanter of the femur at the hips. The height range for females was 152–182 cm, and for males was

172–198 cm. None were notably over- or underweight. Average female shoulder and hip widths were 39.1 ± 1.9 cm and 34.9 ± 1.9 cm, respectively, for the average height of 166.1 ± 7.7 cm. The equivalent male dimensions were a shoulder width of 45.4 ± 1.7 cm, a hip width of 37.0 ± 1.6 cm, and a height of 180.4 ± 6.7 cm (variability is expressed as standard deviation from the mean). By using this information, corresponding dimensions were specified in the computer animations by scaling all figures to the same height (600 screen pixels or 5 deg visual angle at the viewing distance of 182 cm), and defining their physique as either characteristically female, male, or numerically midway between female and male dimensions (androgynous). Although varying structure had consequences for the absolute position of the elbows, wrists and knees, their location relative to the shoulders and hips always remained constant. Manipulation of structure did not affect the position of the head and ankle dots, or limb and torso lengths.

Regarding dynamic information, only lateral movements, most evident in front and rear views of the figure, were varied as a potential source of gender information. Feminine and masculine gaits were specified by the lateral excursions of the light points corresponding to the head, shoulders and hips. Because movements of the limbs are a function of the motion of the torso, lateral shoulder movements were also expressed in the elbows and wrists, and a fraction of the hip movements was expressed in the knees. There was no lateral excursion of the ankles. Feminine synthetic gaits were specified by peak-to-peak lateral excursions of the head, shoulders and hips of 6, 6 and 9 arcmin, respectively (± 0.5 arcmin to allow for quantization errors at the limit of display resolution). Corresponding excursions for masculine movements were 9, 6 and 6 arcmin. As with information about physique, a third androgynous figure was designed with parameters midway between the extremes for each sex, where lateral displacement of the head, shoulders and hips was 7.5 arcmin.

In the sagittal plane, all movements of the figures were identical, with the intention of producing a natural gait without particular bias to female or male characteristics (Murray *et al.* 1964, 1970). The movements included arm swing (31.5 deg about the shoulder, 29 deg about the elbow), leg swing 45 deg about the hip with an 8 deg anterior bias, 67 deg about the knee), stride length (130 arcmin), and the elliptical motion of the shoulder and hip dots (x, y radii for shoulders = 4.5, 1.5 arcmin; hips = 5.5, 2.5 arcmin). In addition, the vertical ‘bounce’ of the gait, evident in the y -axis excursions of all the lights, had a pre-determined 4 arcmin excursion.

A total of five walking figures were synthesized, offering varied structural and dynamic information regarding gender: (M,m), male torso, male body sway; (F,f), female torso, female body sway; (M,f), male torso, female body sway; (F,m), female torso, male body sway; and (A,a), androgynous torso, androgynous body sway. The first two conditions displayed walkers with matching physique and movement, the second two conditions involved mismatched

physique and movement, and the last condition displayed a walker with physique and movement cues intermediate between male and female.

All five walking figures were generated at two viewing angles, 41.8 deg and 90 deg (where 0 deg represents a sagittal view of a right facing figure, and 90 deg a front view). The symmetry of the projection technique was such that all but the sagittally viewed figures could be perceived as walking either towards or away from the observer. The 90 deg projections of figures in the frontal plane contained maximum gender information, from both body dimensions and lateral movements of gait. At the 41.8 deg angle, lateral dimensions and movements were foreshortened to two thirds of their maximum extent ($\sin 41.8 \text{ deg} = 0.67$). At 0 deg, none of the independently varied gender information was available. Only the androgynous figure was presented at 0 deg (all figures were identical at this angle).

(iii) *Design and procedure.* Experimental sessions presented 15 trials of the 11 conditions: (4 walking figures \times 2 projection angles) + (1 walking figure \times 3 projection angles). Light points marking the joints were bright on a uniform dark background. A 6 deg \times 6 deg white outline border was present continuously. Stimulus presentation order was randomized, as was the starting frame of the step cycle. Each stimulus was displayed for 70 frames (1 step cycle = 40 frames). The frame duration of 33.3 ms generated walkers with a reasonably normal free-speed cadence of 90 steps per minute and velocity of 1.17 m s^{-1} (Whittle 1991, p. 136). Observers were required to give a binary 'male' or 'female' response as to the walker's gender, by means of two response keys, recorded by the computer. A brief practice session familiarized observers with the display. All eight participants completed four separate sessions, giving a grand total of 480 gender judgements per stimulus (8 observers \times 4 sessions \times 15 trials).

(b) Results

Figure 1 summarizes the mean gender identification responses for the eight observers to each figure. Analysis of variance, using the arcsine transformation for Bernoulli trials, reveals a highly significant effect of figure type ($F_{4,28} = 40.21$, $p < 0.0001$). The effect of projection angle was non-significant, but its interaction with figure condition was highly significant ($F_{4,28} = 24.77$, $p < 0.0001$). The sex of the observer was not a significant source of variance.

At the 90 deg angle, it is clear that the cue for reliable gender discrimination is body sway rather than torso structure. A Newman-Keuls *post hoc* comparison of the 90 deg treatment means reveals that the (F, f) and (M, f) figure conditions are not significantly different from each other, nor are the (F, m), (M, m) and (A, a) conditions. There is, however, a significant difference between these two subsets of homogeneous means ($p < 0.01$).

For projections of 41.8 deg, although two thirds of the relevant information is still accessible, gender

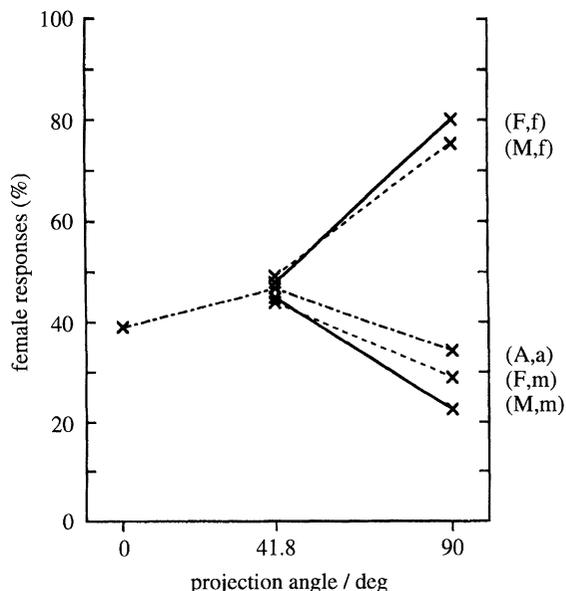


Figure 1. Results of Experiment 1, showing mean percentage of female responses as a function of viewing angle, in five different biological motion displays. See text for details of stimuli.

discrimination is very poor. None of the 41.8 deg treatment means are significantly different from each other (Newman-Keuls comparison), nor do any of the means with their associated standard errors fall wholly beyond the limits of chance responding (cumulative binomial probability theory, chance range = 45.6–54.4% female responses, $p < 0.05$).

As anticipated, gender identification is more accurate when the figure projections are at 90 deg. The 41.8 deg and 90 deg treatment means differ significantly from each other in the following figure conditions: (F, f) $p < 0.025$; (M, f) $p < 0.05$; and (M, m) $p < 0.025$ (Bonferroni *t*-test using a familywise error rate suitable for five pairwise comparisons). The 41.8 deg and 90 deg views did not differ significantly in the (F, m) and (A, a) conditions.

A final interesting aspect of the data is the slight but significant bias towards identifying the androgynous (A, a) figures as male, at projection angles of 0 deg and 90 deg (cumulative binomial probability, $p < 0.05$). This is despite the fact that at 0 deg the physique and lateral movements of the figure cannot be seen, and at 90 deg these variables are midway between those used to characterize females and males. We calculated bias by using the signal detection techniques described in Macmillan & Creelman (1991). Assuming that subjects decide whether to respond 'male' or 'female' by comparing observations with an internal criterion, they showed a pronounced bias in favour of 'male' responses, so that (A, a) figures fell on the male side of the criterion.

(c) Discussion

The most striking feature of the results relates to 90 deg projections, where average gender discrimination accuracy was 79% when physique and lateral movements of the figure were matched for gender. Because accuracy only decreased by 6% when con-

tradiotory structural cues were present, lateral components of locomotion are evidently the more salient source of gender information. Lateral shoulder movements defining our figures' feminine and masculine gaits were based on data available in Murray *et al.* (1970). Unfortunately we could find no data relating to gender differences in hip sway, so male hip sway in the displays was set equal to female shoulder sway, and male shoulder sway was set equal to female hip sway. The possibility arises that our displays contained exaggerated body sway cues. In the absence of normative data it is impossible to rule out this possibility entirely. Subjectively, the figures did not seem to move in an exaggerated way. Before the experiment, subjects were given no information about possible gender cues, and afterwards they were not sure of the cues they used. Some mentioned 'hip swivel' rather than sway, others described a 'male swagger' or shoulder breadth cue. The sway cue was not clearly detectable to naive observers.

The reason for the collapse in discrimination at the 41.8 deg viewing angle is unclear. One possibility is that, at an oblique viewing angle, shoulder and hip movements contain two components, a front-to-back component and a side-to-side component. The front-to-back component (visible in side views) does not support reliable gender discrimination, but the side-to-side component (visible in frontal views) does support gender discrimination, as the data show. In the absence of perspective or binocular cues to view angle in oblique views, there may be insufficient information to estimate the separate contributions of the two components to resultant hip and shoulder movements, precluding reliable discriminate gender.

A possible reason for the observer's insensitivity to the structurally determined centre-of-moment is that its position is not sufficiently different in our female and male figures. The mean shoulder to hip width ratios calculated from our 20 female and 20 male participants were 1.12:1 for females, and 1.23:1 for males. These values are not consistent with the corresponding ratios of 0.99:1 and 1.1:1 quoted by Barclay *et al.* (1978), obtained from a smaller sample. The most obvious reason for the discrepancy is the fact that Barclay *et al.* (1978) measured the biacromial width of the shoulders and the bi-iliac width of the hips (marked by the most laterally protruding points of the scapula and the iliac crest, respectively). Our own measurements were taken somewhat lower, and included the greater tuberosity of the humerus in the shoulder width, and the greater trochanter of the femur in the hip measurement. The intention was to define the intersection of the joints at the pivot points of the limbs. However, it is important to note that Barclay *et al.*'s measurements place the centre-of-moment at 2.63% of the torso length higher in females than in males, and our measurements place the centre-of-moment at 2.33% higher, so structural cues are very similar in the two experiments. The visual angle subtended by our figures was also similar to that used by Cutting & Kozlowski (1977).

Cutting *et al.* (1978) found that gender discrimination in their displays did not exceed chance for

exposure durations below 4.4 s (see Introduction). As a means of gauging the salience of our dynamic cue, and as a preliminary to Experiment 3, Experiment 2 tested gender discrimination as a function of exposure duration. We varied both the number of animation frames presented and the duration of each frame, since both affect exposure duration.

3. EXPERIMENT 2. TEMPORAL PROPERTIES OF GENDER RECOGNITION

(a) Method

(i) *Subjects.* Three observers participated in Experiment 2: the female experimenter, and one female and one male from the previous experiment, both naive as to the purpose of the experiment.

(ii) *Stimuli.* Equipment and stimulus specifications were unchanged. However, all figures were now specified by androgynous shoulder and hip dimensions, and were only shown at 90 deg projection angles. As before, peak-to-peak lateral excursions of 6, 6 and 9 arcmin (for the head, shoulders and hips, respectively) described feminine locomotion, and excursions of 9, 9 and 6 arcmin defined masculine synthetic gait. Only differences in lateral body movements, not physique, allowed gender discrimination.

(iii) *Design and procedure.* Two temporal parameters were varied: the number of frames displayed (10, 15, 20 or 30), and the exposure duration of each frame (16.6 ms, 33.3 ms or 49.9 ms). Temporal details of the 12 stimuli are listed in table 1, with the corresponding cadence and number of step cycles also shown. None of the figures' movements were adjusted to make the gait appear natural at the extremes of cadence.

All observers completed four sessions, each requiring 240 gender discriminations: 2 lateral movements \times 3 frame durations \times 4 number of frames \times 10 trials. The starting frame of each trial was randomized, as was the order of presentation of successive stimuli. No practice trials were given.

(b) Results and discussion

A bias in favour of 'male' responses was found in Experiment 1, so d' was adopted as a bias-free measure

Table 1. *Presentation duration for the 12 stimulus combinations of Experiment 2*

		Frame duration/ms		
		16.6	33.3	49.9
		cadence/steps per minute		
frames	step cycles	180	90	60
10	0.25	167	333	500
15	0.375	250	500	750
20	0.5	333	667	1000
30	0.75	500	1000	1500

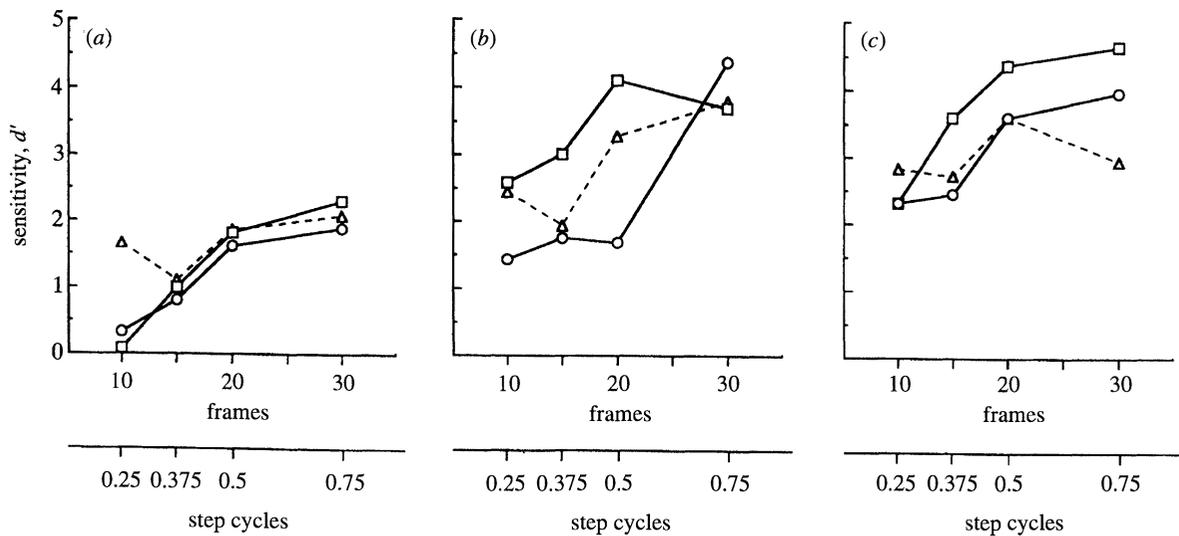


Figure 2. Results of Experiment 2, showing gender sensitivity as a function of the number of frames presented. Data from three subjects are shown: (a) TR, (b) HT, and (c) LM. Symbols specify frame duration: 16.6 ms (circles), 33.3 ms (squares) and 49.9 ms (triangles).

of sensitivity in this and the following experiment. Figure 2 plots sensitivity as a function of the number of frames presented for each subject, with frame duration or cadence as the parameter. Gender identification improved as the number of frames presented increased, but was reliable even for presentations containing only one quarter of a step cycle (mean $d' = 1.01$ at 10 frames, approximately 70% correct). There was a tendency for performance to be highest at a frame duration of 33.3 ms (squares in figure 2), corresponding to a natural gait for the normal free-speed cadence of 90 steps per minute.

Performance is clearly much better than that reported by Barclay *et al.* (1978) using videotaped side views of actors. They obtained 66% correct discrimination when two complete step cycles were presented. There are several gender differences in gait, as mentioned in the Introduction, so it is not clear what cues Barclay *et al.*'s observers used. In our synthetic displays the only cue available was lateral body sway (invisible in Cutting's stimuli). Given the relatively high levels of discrimination in our experiment, this cue is apparently more powerful than the cues available in Cutting *et al.*'s stimuli.

4. EXPERIMENT 3. LATERAL VELOCITY AND GENDER RECOGNITION

Having established that a fraction of a step cycle is sufficient to identify a walker's gender, Experiment 3 investigated which, if any, part of the step cycle is most informative about gender. Gender-specific movements are periodic, with lateral sinusoidal displacements occurring once every step cycle.

Figure 3 plots lateral head, shoulder and hip position of synthetic walkers during the step cycle, visible in frontal projections of androgynous figures. At 0 deg and 180 deg in the cycle both feet are in contact with the ground, but at 90 deg and 270 deg one leg is in mid-swing forward. The shoulders and hips sway

laterally towards the weight-bearing leg, but note the gender differences already discussed: male shoulders move more than female, but female hips move more than male. Given this periodicity in movement, it is reasonable to expect that the cue will also vary sinusoidally. If discrimination performance depends on positional cues then it should be optimal for brief displays which include the extremes of shoulder and hip position (i.e. at 90 deg and 270 deg), because the male-female difference is greatest here. Similarly, discriminability will be poorest at 0 deg and 180 deg because positional differences are minimal. Alternatively, if performance depends on velocity cues then it should be optimal at 0 deg and 180 deg, where the male-female velocity difference is greatest (shown by slopes of the curves in figure 3), and poorest at 90 deg and 270 deg, where the dots are momentarily stationary as they reverse direction. Experiment 3 tested these competing predictions.

(a) Method

(i) *Subjects.* Data were obtained from the three participants of Experiment 2.

(ii) *Stimuli.* All figures were shown walking at 90 deg projection angles, with the usual female or male lateral movements (as in figure 3) assigned to an androgynous physique. Frame duration was a constant 33.3 ms, producing a natural gait for the normal free-speed cadence of 90 steps per minute. The number of frames displayed, and therefore stimulus duration for each sequence, was also constant. Depending upon the observer, it was either 6 frames (stimulus duration = 200 ms), 7 frames (233 ms), or 11 frames (367 ms), and was chosen for each subject to avoid ceiling and floor effects.

(iii) *Design and procedure.* The starting frame of each walking sequence was independently varied. Assuming the 40 frames that constitute a single step cycle are

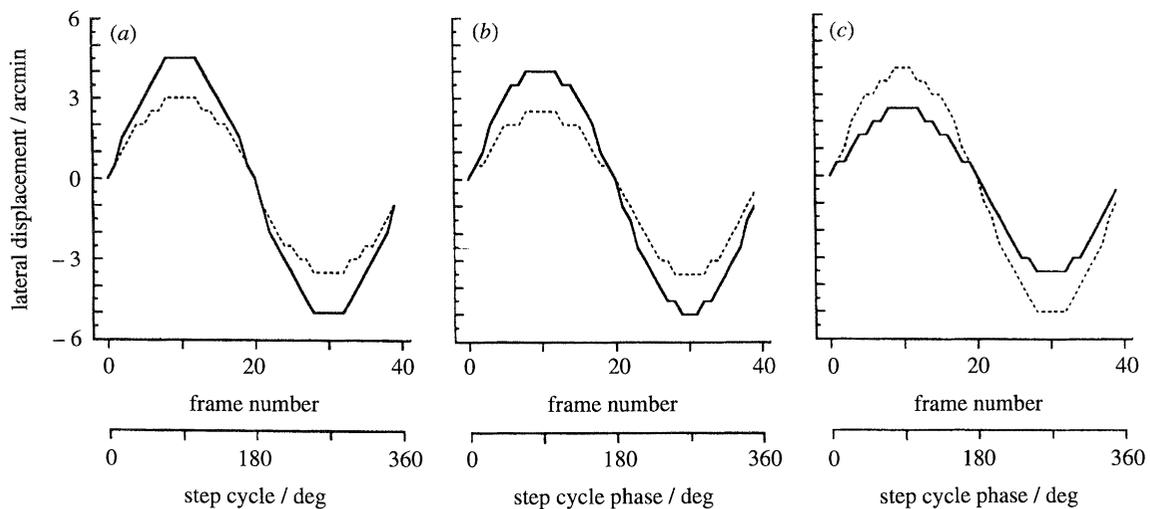


Figure 3. Lateral displacement of (a) head, (b) shoulder and (c) hip dots as a function of step cycle phase. Solid curves represent male figures, broken curves represent female figures. Values are plotted in minutes of arc, as seen in frontal projections of experimental stimuli.

labelled from 0 through to 39, the starting frame of each trial was randomly assigned as either: frame 0, 5, 10, 15, 20, 25, 30 or 35 (0, 45, 90, 135, 180, 225, 270 or 315 deg).

All observers made binary female–male responses to a total of 720 synthetic walkers: 2 lateral movements \times 8 starting frames \times 15 trials \times 3 sessions.

(b) Results and discussion

The solid lines in the three graphs of figure 4 represent individual observers' sensitivity (d') to the gender of synthetic walkers as a function of step cycle phase. All observers show the same sinusoidal variation in performance, with maximum discriminability occurring at the start or end and midpoint of the cycle (0 deg and 180 deg). Results therefore support predictions based on velocity differences rather than predictions based on positional differences. Figure 3 shows that although there is no difference between male and female walkers in terms of dot position at the start and midpoints of the cycle, there is clearly a difference in velocity. To provide a quantitative comparison between data and predictions, we computed the difference between male and female dot velocities, averaged over hips and shoulders (regardless of sign), and over the fraction of the step cycle each observer saw at each starting phase. The broken lines in figure 4 plot these velocity differences (scaled arbitrarily so that maximum velocity difference coincides with $d' = 3.0$; the plots are not identical because stimulus duration varied between observers). There is close agreement between observers' sensitivity and velocity variations, suggesting that dynamic information underlies gender discrimination. Expressed as a percentage, the male–female velocity difference was actually constant across the step cycle at 33%. Maximum dot velocity at the mid- and endpoints of the step cycle was 0.4 deg s^{-1} . Orban *et al.* (1984) reported that the differential threshold for velocity is about 15–20% at this velocity, and rises sharply at lower velocities, so the male–female velocity difference

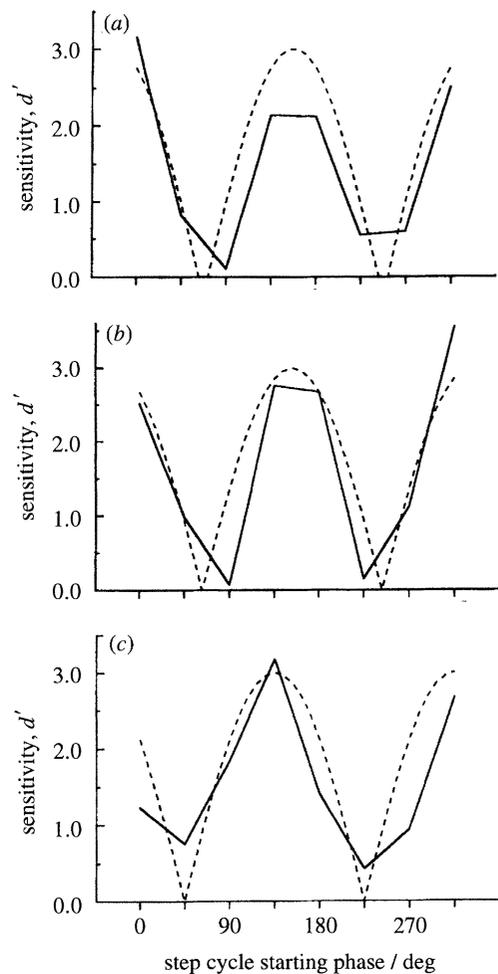


Figure 4. Results of Experiment 3 showing gender sensitivity as a function of step cycle starting phase for three subjects: (a) LM, (b) HT, and (c) TR. Solid curves represent data, broken curves represent predictions based on male–female differences in shoulder and hip dot velocity at each phase. See text for details.

was almost certainly not detectable at the one-quarter and three-quarter points of the step cycle where velocity approached zero.

Our female and male synthetic walkers were identical in all respects except lateral sway but, as mentioned in the Introduction, there are several gender differences in the gait of real walkers, so we cannot be sure how much weight the sway cue carries in identifying the gender of real walkers. However, Cutting *et al.*'s videotapes of real walkers presumably contained multiple cues (but not sway), but they were not sufficient to allow discrimination at the levels reported here.

The present study emphasizes the importance of hip and shoulder movements for gender judgements. A recent study (Mather *et al.* 1992) found that simpler judgements about the direction that synthetic walkers faced depended particularly on motion of the extremities (wrists and ankles). It seems that biological motion displays offer a multiplicity of dynamic cues about various aspects of the walking figures. Different cues are used for different visual tasks, and systematic study of biological motion perception with synthetic walkers offers a way to identify these cues and gauge their importance.

5. CONCLUSIONS

For dynamic frontal projections of human biological motion, gender discrimination is mediated by lateral body sway in shoulders and hips, and depends on dynamic motion cues rather than positional information. We conclude that this sway cue is more powerful than the structural cue based on torso shape (described by Barclay *et al.* (1978)) because: (i) in figures pitting the dynamic cue against the structural cue, gender perception is governed by the dynamic cue; and (ii) performance mediated by the dynamic cue is very reliable, even in displays containing a fraction of a step cycle, whereas performance mediated by structural cues is only moderately reliable for displays containing two complete step cycles. The possibility arises that observers in Barclay *et al.*'s (1978) experiments using side views based their judgements on the relative velocities of shoulder and hip dots.

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