From body form to biological motion: Apparent velocity of human movement biases subjective time

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Abstract

Two experiments investigated time perception during apparent biological motion. Pictures of initial, intermediate and final positions of a movement were presented, with six inter-stimulus-intervals. Movement path was manipulated by changing sequential order of body postures. Increasing path length produced an increase in perceived movement velocity. As an implicit measure of apparent movement dynamics, we also asked participants to judge the duration of a frame surrounding the stimuli. Longer paths, with higher apparent movement velocity produced shorter perceived durations. This temporal bias was attenuated for non-body (Experiment 1) and inverted-body (Experiment 2) control stimuli. We propose an automatic top-down mechanism of biological motion perception that binds successive body postures into a continuous percept of movement. We show that this mechanism is associated with velocity-dependent temporal compression. Furthermore, this mechanism operates on-line, bridging the intervals between static stimuli, and is specific to configural processing of body form.

INTRODUCTION

The human brain has dedicated mechanisms for visual processing of human body form and human movement (Downing, Jiang, Shuman, & Kanwisher, 2001; Giese & Poggio, 2003). Traditionally, research on visual perception of human movement has taken two perspectives: S*tructure from motion* studies focused on movement kinematics. They show that a clear percept of biological motion can arise despite minimal information about body form. Observers can readily identify human actions from point-light displays (Johansson, 1973; Blake & Shiffrar, 2007;).

In contrast, *motion from structure* studies show that static "snapshots" of bodies produce illusions of movement which bias memory ("representational momentum", Freyd, 1983) and perception ("apparent biological motion", Shiffrar & Freyd, 1990, 1993). In representational momentum studies, static pictures implying movement are presented (e. g. a snapshot of a person jumping). When asked to identify a previously presented picture, recognition is biased towards the implied but unseen end position of the movement (Verfaillie & Daems, 2002, Kourtzi & Shiffrar, 1999). During apparent biological motion (Chatterjee, Freyd, & Shiffrar, 1996; Shiffrar & Freyd, 1990, 1993; Grosjean, Shiffrar, & Knoblich, 2007), participants experience *seeing* a biological movement linking two static images of initial and final positions, as long as the inter-stimulus interval is consistent with actual movement duration. Conversely, at very short time intervals, an impossible movement is seen.

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Motion-from-structure studies show that static images of the body are sufficient to trigger dynamic representations of movement, that include information about kinematics and the *time course* of action (Grosjean et al., 2007). This view implies that appropriate sequences of body postures should induce percepts of movement *duration* that reflect apparent movement dynamics, rather than the objective temporal gap between successive postures. Thus apparent biological motion and the passage of subjective time may be linked. Importantly, subjective time during apparent motion would then provide a purely implicit measure that should reveal whether apparent motion *automatically* induces a dynamic percept of movement. This is important because explicit judgements of apparent movement used in previous studies presumably involve conscious attempts to "see movement", introducing a contribution of memory for plausible movements, rather than a change in perception.

We therefore investigated whether the dynamic properties of apparent movement are reflected in the subjective duration of a sequence of static body postures. If apparent biological motion only reflected seeing a plausible movement path, subjective durations for longer paths should dilate, since longer movement paths presumably take more time (Shiffrar & Freyd, 1993). However if apparent biological motion included a percept of movement *velocity*, longer movement paths, which are naturally covered at higher speeds (Flash & Hogan, 1985) might in fact appear to take less time than slower movements. Therefore, the direction of time distortions informs about the *content* of the apparent biological motion percept and can reveal the fundamental properties encoded in representations that underlie biological motion perception. To investigate whether these effects are specific to apparent *biological* motion, we compared body and non-body stimuli (Experiment 1). To investigate whether they depend on a configural representation of body form (Reed, Stone, Bozova, Tanaka, 2003), we compared upright and inverted body images (Experiment 2).

METHODS

Participants

18 participants took part in Experiment 1 (13 female, 16 right-handed, mean age 26 years) and 18 new participants in Experiment 2 (11 female, 16 right-handed, mean age 25). Participants were paid £7.50 or received course credit.

Stimuli and Conditions

Five movements were professionally choreographed and captured digitally (for a full list of stimuli, see supplementary material). Three greyscale pictures were selected to display initial (1), intermediate (2) and final (3) snapshots from each movement. Any order of the three pictures produced a feasible movement. Thus, the apparent movement path depended on the sequential order of otherwise identical static postures (Figure 1).

We used four of the six possible sequences, namely those matched for initial postures: Placing the intermediate posture in the final position produced an apparent movement path that was approximately 1.5 times longer than when the intermediate posture occurred in second position.

Non-body control stimuli (Experiment 1) were created by degrading spatial resolution, so that overall human form was no longer recognizable. In Experiment 2, control stimuli were created by inverting each body picture. Pictures subtended approximately 3.1° of visual angle. Practice trials used additional pictures not shown in the main experiments.

Experimental Design and Procedure

The time course of each trial is shown in Figure 2. Trials started with a fixation cross, displayed for a random interval between one and two seconds. This was followed by a sequence of three pictures, each displayed for 100 ms. Picture offset and onset were separated by ISIs between 50 and 300 ms, in steps of 50 ms. ISIs between first and second and second and third picture were always the same. A white rectangle surrounded the stimuli, and remained visible throughout the picture sequence, including the ISIs. Thus overall duration of the rectangle varied between 400 and 900 ms, in steps of 100 ms.

Participants' task was to judge the duration of the white rectangle. Thus, the pictures presented were task-irrelevant, unlike in previous apparent motion studies. Participants were informed that the white rectangle would be presented for shorter and longer durations. They pressed a key to indicate if a given rectangle duration was relatively short or long, compared to all other durations experienced in the task (2AFC for interval durations, or 'temporal partition': Wearden & Ferrara, 1995, 1996). In temporal partition, no standard duration is presented for direct comparison. In this case participants establish a bisection point for short and long durations that typically centres around the arithmetic mean of the duration distribution. For unbiased performance, this corresponds to a PSE (point of subjective equality) of 175 ms in our experiments. For the duration judgement task, participants in both experiments completed four blocks. Each block consisted of 240 trials (10 body and control picture sets arranged in 4 sequences at 6 ISI levels). The order of trials was randomized per block and participant.

In Experiment 2, duration judgements were followed by an additional block, in which participants explicitly judged the velocity of the apparent movement. They pressed a key according to whether a given sequence of postures produced a relatively slow or fast apparent movement, compared to all other posture sequences encountered during the task. In order to prevent any explicit effect of velocity perception on duration judgements, the velocity task in Experiment 2 was always performed *after* the duration judgement task. Prior to both tasks participants completed a short practice session.

Data analysis

In both experiments participants were able to establish a stable bisection criterion very quickly: The pattern of results was the same regardless of whether the first block was excluded from analysis or not. Accordingly, all four blocks were included in the analysis. We fitted psychophysical curves to relate the percentages of "long" responses (duration judgement) or "slow" responses (velocity judgement) to overall stimulus duration, using logistic regression. We compared the PSE for body and non-body (Experiment 1) and upright and inverted sequences (Experiment 2). A repeated measures ANOVA on the PSE was conducted with factors of picture type (body vs. non-body/ upright vs. inverted), and implied movement path (short vs. long). For both experiments the data of two participants was excluded because their overall performance on the duration judgement task never exceeded 50% correct, so PSEs could not be calculated.

RESULTS

Experiment 1: Implicit duration judgements

Analyses of PSEs showed that sequences implying longer movement paths were perceived to take less time than sequences implying shorter paths ($F(1, 15) = 47.2$, $p < .001$, $\eta^2 = .76$), see figure 3A. This difference was more pronounced for body sequences than non-body sequences, leading to a significant interaction with picture type ($F(1,15) = 8.4$, $p = .011$, $\eta^2 = .36$), but there was no overall difference between body and non-body stimuli ($F(1,15) = 0$,

p = n. s). Mean PSE for body (non-body) sequences was 160 ms (171 ms) for short path sequences and 193 ms (183 ms) for long path sequences.

Experiment 2: Implicit duration judgements

The pattern of results was very similar to experiment 1, see figure 3B. Subjective time during posture sequences with longer paths was contracted compared to short path sequences ($F(1,15)$ = 13.2, p = .002, η^2 = .47), see figure 3B upper panel. Based on our finding of body-specificity in experiment 1, we predicted an interaction between implied movement path and body orientation in experiment 2, with the temporal bias being more pronounced for upright than inverted bodies. An interaction in the predicted direction was indeed found ($F(1,15)$ = 3.3, p = .044, one-tailed, η^2 = .18). There was no main effect of body inversion ($F(1,15)$ = 0.48, p = n. s., η^2 = .03). The mean PSE for upright (inverted) sequences was 151 ms (161 ms) for short movement paths and 183 ms (182 ms) for long movement paths.

Experiment 2: Explicit velocity judgements

For the velocity judgement task of experiment 2 (figure 3B, lower panel), one further subject was excluded since overall performance never exceeded the 50% threshold. Overall, apparent movements with longer paths were perceived as faster than sequences with shorter paths ($F(1,14)$ = 17.5, p = .001 η^2 = .55). As for implicit duration judgement, this effect was significantly attenuated if sequences were inverted ($F(1,14)$ = 5.8, p = .03, η^2 = .29) and there was no main effect of inversion on velocity judgements ($F(1,14)$ = 1.1, p = n. s.). Mean PSE for upright (inverted) body sequences was 127 ms (147 ms) for small movement paths and 182 ms (183 ms) for long movement paths.

The ratio between short and long movement paths created by reordering the postures sequences was 1:1.5 in both experiments (see methods). This allowed us to test how apparent path ratio translated into perceived time and velocity. Averaged across participants in both experiments, the mean short:long PSE ratio for implicit duration judgements of upright body sequences was 1.56 which did not differ from the 1:1.5 ratio for movement path ($T(31$ = 0.42 , p = n. s.). In contrast, the PSE in the control conditions (non-body/inverted) was 1.11, and significantly lower than 1.5 ($T(31)$ = −15.7 , p < .001). Thus, changes in movement path caused proportional changes in subjective time, but only for upright body stimuli. The same result pattern was observed for explicit velocity judgements in experiment 2. The mean slow:fast PSE ratio for upright bodies was 1.98 and not significantly different from the implied movement path ratio of 1:1.5, ($T(14)$ = 1.1 , p = n. s.). Conversely, the mean slow:fast PSE ratio for inverted bodies was 1.26 and significantly lower than 1.5 ($T(14)$ = −2.8, p = .014). Therefore, increasing movement path length between upright body postures by a factor of approximately 1.5 lead to a contraction of subjective time by a numerically similar factor, and produced apparent movements that appeared approximately twice as fast.

DISCUSSION

Reordering a sequence of three body postures produced apparent movements with different path lengths. This produced directly proportional changes in perceived velocity and inversely proportional changes in time perception. That is, longer paths produced faster apparent movements and a contraction in subjective time compared to posture sequences implying shorter movement paths. If duration judgments were based directly on movement path, longer movements should produce a dilation of subjective time, since larger movements may be assumed to take more time than smaller movements (Shiffrar & Freyd,

1993). In contrast, we observed a temporal compression effect, suggesting that velocity is a more salient perceptual feature of apparent biological motion than movement path.

Moreover, apparent biological motion in our study occurred automatically: the bodies displayed in our picture sequences were entirely irrelevant to the participants' task of judging durations. Nevertheless, time perception was clearly affected by features of the apparent movement, in this case velocity. This excludes an explanation of our effects based on explicit knowledge about plausible movement paths or voluntary motor imagery. Previous studies of apparent biological motion explicitly requested participants to see motion (Chatterjee et al., 1996; Shiffrar & Freyd, 1990, 1993; Grosjean et al., 2007). It is then difficult to distinguish perception from suggestion and intention.

Importantly, temporal bias and apparent velocity are specific to upright body postures, since they are reduced for non-bodies and inverted bodies. Therefore our findings suggest an automatic top-down mechanism of biological motion perception that depends on configural processing of human body form (Reed et al., 2003). This top-down process partially compensates for the lack of continuous visual input (i.e., the missing frames in between our static postures) known to drive bottom-up biological motion perception (Giese & Poggio, 2003; Thornton et al., 2002; Mather, Radford, & West, 1992). This filling-in process infers dynamic movement from successive static postures and produces a percept of movement velocity. The distortion of perceived time is a direct result of the on-line generation of a velocity representation. Our picture sequences provided only form and time information, to which the observer's mind adds movement and speed percepts. This process may play an important role in the prediction of observed actions, when bottom-up sensory evidence is insufficient (Verfaillie & Daems, 2002; Graf et al., 2007). Although our study is purely behavioural, previous research on apparent biological motion using neuroimaging methods suggests that this top-down process may have a motor component (Stevens et al., 2007).

We use time perception as an implicit measure of the dynamic properties of (apparent) human movement. However, subjective duration is influenced by other factors such as selective attention to novel, 'interesting' stimuli (Tse, Intriligator, Rivest, & Cavanagh, 2004). However, selective attention for body but not for non-body pictures or other lower-level visual processing differences cannot explain our findings, since the direction of the temporal bias depends on rearranging the *same* body postures in a different sequential order. Specifically, longer movement paths produce *larger* PSEs than their non-body controls, while shorter paths produce *smaller* PSEs than their non-body controls. Therefore, the temporal bias does not depend directly on static stimulus properties, but on the top-down processes that reconstruct movement velocity in the absence of actual movement.

To conclude, we suggest that an automatic top-down mechanism binds static snapshots of body postures into a continuous percept of biological motion (see figure 4) This mechanism subjectively contracts the duration of the apparent movement with increasing perceived velocity, but does not rely on conscious attempts to "see" movement. However, it depends on configural processing of human body form. Our results provide the first strong psychophysical evidence for the direct link between body form and biological motion perception previously hypothesised by computational theories (Giese & Poggio, 2003).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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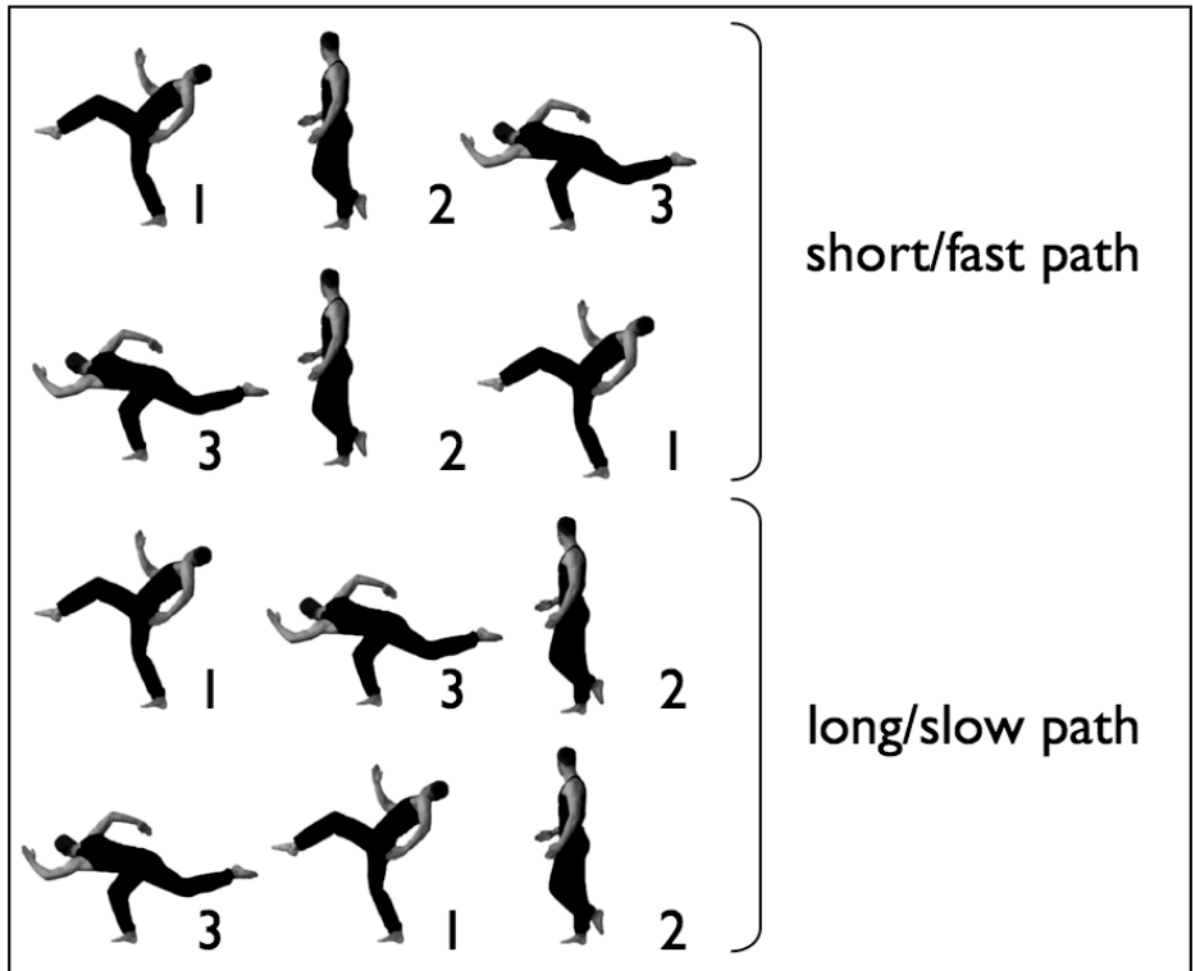
Figure 1.
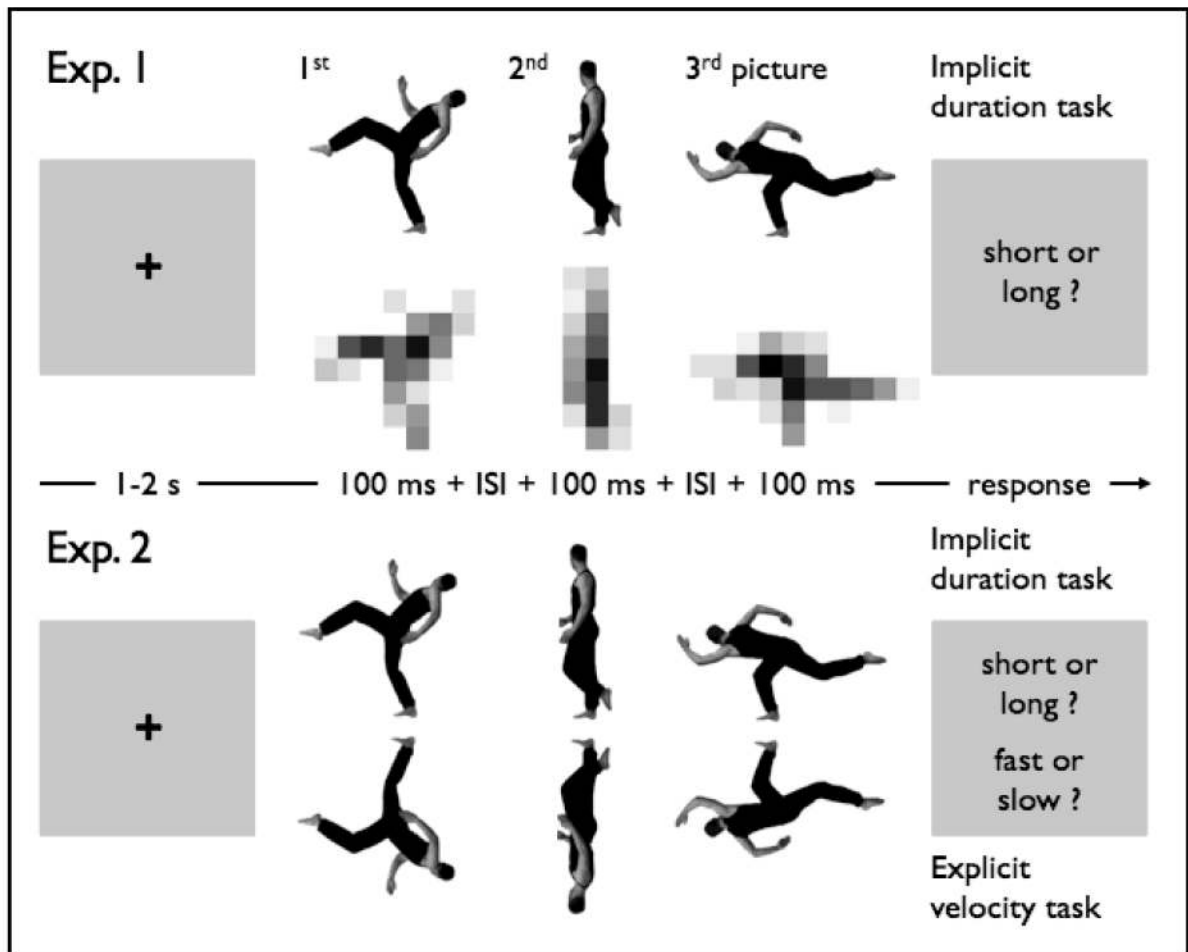Examples of short path/slow movements and long path/fast movements.

Figure 2.
Trial-sequences in experiment 1 (body, non-body), and 2 (upright, inverted).
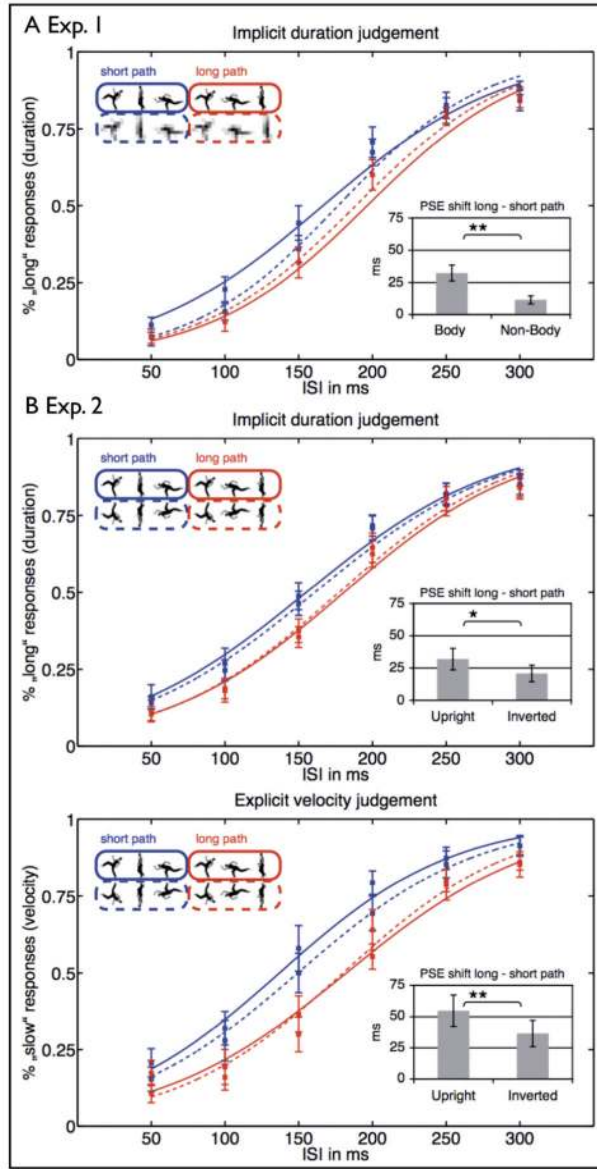
Figure 3.
Mean percentage of "long" responses (error bars depict standard error) and averaged psychophysical curves for duration judgements in Experiment 1 (A) and 2 (B, upper panel) and "slow" responses for velocity judgements in Experiment 2 (B, lower panel). Colour codes apparent path length (short path in blue, long path in red). Bar graphs display the PSE shift for long - short apparent paths (** p < .05, two-tailed, * p < .05, one-tailed).
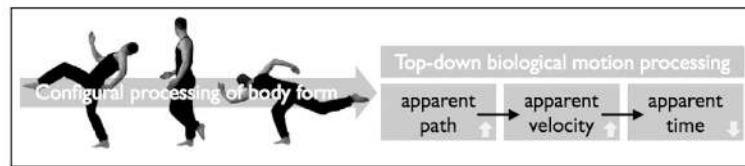
Figure 4.
A possible mechanism for top-down processing of biological motion.