Incidental Processing of Biological Motion

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Summary

The successful detection of biological motion can have important consequences for survival. Previous studies have demonstrated the ease and speed with which observers can extract a wide range of information from impoverished dynamic displays in which only an actor's joints are visible [1–2]. Although it has often been suggested that such biological motion processing can be accomplished relatively automatically [1–5], few studies have directly tested this assumption by using behavioral methods. Here we used a flanker paradigm [6–8] to assess how peripheral "to-be-ignored" walkers affect the processing of a central target walker. Our results suggest that task-irrelevant dynamic figures cannot be ignored and are processed to a level where they influence behavior. These findings provide the first direct evidence that complex dynamic patterns can be processed incidentally, a finding that may have important implications for cognitive, neurophysiological, and computational models of biological motion processing.

Results and Discussion

For many species, the successful detection and interpretation of movement patterns generated by other living creatures (biological motion processing) is of prime importance for survival. Such processing can help an animal avoid predators, detect prey, assess the intentions of an approaching rival, or identify a potential mate. Consistent with this role, numerous laboratory studies have demonstrated that the human visual system is highly sensitive to biological motion even when visible cues are reduced to only a few moving points of light attached to the major body joints [1–2, 9–13]. These so-called point-light figures have become a standard tool for exploring biological motion, because they remove all but a few static cues that might aid visual processing. Interestingly, other species also appear to be able to process such point-light displays [14–17].

The ecological significance of biological motion perception, its appearance across a range of species, and the apparent speed and efficiency of processing have led a number of researchers to propose that biological

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motion processing is accomplished via low-level, passive mechanisms operating in an automatic, stimulus-driven manner [1–5]. However, more recently, several studies have also highlighted the important role that top-down mechanisms involving prior knowledge [10, 18–19] and attention [20–23] might play.

In the natural environment, there is little reason to doubt that both top-down and bottom-up mechanisms contribute to the successful processing of biological motion. However, to better understand how these two types of mechanisms relate to each other and to assess their relative contribution in guiding behavior, it is clearly appealing to design experiments where they can be teased apart. Surprisingly, this has rarely been done [3, 19, 22, 24].

Here we test for the ability to process biological motion in the absence of top-down effects by combining point-light figures with a classic flanker-interference paradigm [6]. In flanker tasks, observers make rapid responses to a central target item that can either be presented alone or in the presence of additional surrounding items. The critical finding is that when the to-be-ignored flankers map on to a response that conflicts with the current target, speed and accuracy is worse than when the flankers are absent or are compatible with the target. Such tasks are highly appealing, because they provide an indirect method to assess the processing of the flanking items.

Typically, the target and flankers are simple stimuli such as letters or digits, and the observer is explicitly told to ignore the flanking items [6–7]. As shown in Figure 1, in the current study, we presented a central target figure flanked by two or more figures that faced and walked (in place) in the same or different direction to that of the target. By asking observers to report the direction in which the target appeared to walk, we could create both congruent displays (all walkers face the same direction) and incongruent displays (e.g., targets face left, flankers face right). Because the flanking figures are never the target of a response, any influence they have on behavior must be due to incidental processing with the contribution of top-down processes removed or at least substantially attenuated.

In Experiment 1, we used the linear arrangement of figures shown in Figure 1A. Twelve observers recruited from the Tübingen community judged the direction of a central target figure with target-only, congruent, and incongruent trials randomly interleaved. The target faced either left or right equally often. Observers responded extremely quickly and had near-perfect accuracy in this judgment task for all experiments reported. Moreover, because both measures showed nearly identical result patterns, for the sake of space, we discuss only response times in detail. Full tables of results for both measures can be found in the Supplemental Data available with this article online.

The median response times for Experiment 1 are presented in Figure 2. A repeated-measures ANOVA with target-facing (left, right) and condition (target-only, con-
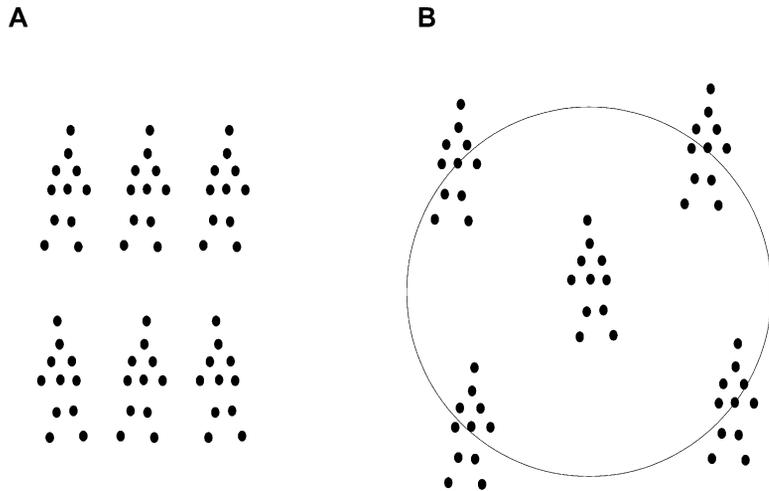
A

B

Figure 1. Overview of Stimuli and Design

In all experiments we used a standard algorithm to generate synthetic point-light figures [39]. Each figure consisted of 11 dots (0.2°), drawn in black on a gray background, and subtended 3.8° in height (head to ankle) and 1.2° in width (at the most extended point of the step cycle). The figures were drawn in profile, facing left or right relative to the observer, and animated with a simulated natural walking speed of 38 strides per minute [40]. The figures were slightly smaller in Experiment 2 and scaled at different eccentricities [25]. The step-cycle of each flanking figure was randomized with respect to each other and the target. In the linear configuration (Panel A), flanking figures appeared directly to the right and left of the target, with adjacent figures 2.4° apart (hip to hip). The example shows a Congruent (top) and Incongruent (bottom) trial with a right facing target. In the clockface configuration (Panel B), four equally spaced windows (4.3° in height x 2.8° in width) were organized around a circle with a radius of 4.3°. The angular offset of the flanker positions around the circle was randomly assigned on each trial. These windows either contained a single coherent figure (shown here) or the local motion of five scrambled point-light figures. The solid circular line has been added for illustration purposes only. Dynamic versions of these figures can be found in the supplementary material.

gruent, incongruent) as within-subjects factors revealed only a main effect of condition [F(2,22) = 33.1, p < .001]. Posthoc comparisons suggest this effect is driven by a walker congruency effect (WCE), with responses on incongruent trials (mean (M) = 593 ms, standard error (SE) = 26 ms) being slower as compared to either responses on congruent (M = 530 ms, SE = 22 ms) [F(3,33) = 38.9, p < .001] or target-only trials (M = 508 ms, SE = 18 ms) [F(3,33) = 71.3, p < .001]. Response-time differences between congruent and target-only trials were also significant [F(3,33) = 4.85, p < .001].

In Experiment 2, we assessed whether the influence of the flanking figures was restricted to the immediate vicinity of the target. Because the flankers were very close to the target in Experiment 1 (within 2.5°), it is possible that observers were unable to ignore them despite our instructions. Thus, we systematically increased the target-flanker separation. We also included a static flanking condition with figures posed at the widest extent of a step cycle, to assess the impact of form-only direction cues. Because the spatial resolution of peripheral vision is much poorer than foveal vision, we scaled flanking figures by a cortical magnification factor [25]. Twenty observers recruited at Brown University judged the direction of a central target with dynamic or static flanking figures presented at five different retinal eccentricities (and appropriately scaled in size relative to the target).

Response times were submitted to a repeated-measures ANOVA with target-facing (left, right), flanker type (dynamic, static), congruency (congruent, incongruent) and eccentricity as within-subjects factors. These data are shown in Figures 3A and 3B. There was a main effect of flanker type, with static trials (M = 523 ms, SE = 3 ms) being slightly faster than dynamic trials (M = 538 ms, SE = 3 ms), F(1,19) = 32.0, p < .001. There was a main effect of congruency, with incongruent trials (M = 542 ms, SE = 3 ms) being slower than congruent trials (M = 519 ms, SE = 3 ms), F(1,19) = 102.0, p < .001. More importantly, however, there was also the significant flanker type × congruency interaction, F(1,19) = 28.6, p < .001, shown in Figure 3C.

There was a main effect of eccentricity, F(4,76) = 32.8, p < .001, as well as significant flanker type × eccentricity, F(4,76) = 4.1, p < .01, and congruency × eccentricity, F(4,76) = 11.6, p < .001, interactions. The three-way flanker type × congruency × eccentricity interaction, however, did not reach significance, F(4,76) = 1.6, p = .17. This suggests that there is a reliable difference between congruent and incongruent conditions for both static and dynamic trials.

To further explore the nature of this difference, we calculated a within-subject WCE by subtracting median incongruent response times (RT) from congruent RTs for each observer, the average of which is shown in Figure 3D. For dynamic trials, there is a clear cost associated with incongruent trials across all eccentricities.
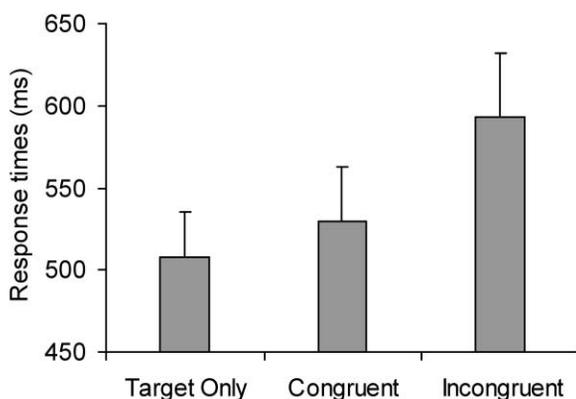

Figure 2. The Walker Congruency Effect

In Experiment 1, both congruent and incongruent flankers led to increased response times relative to the target-only condition. The conflict between the direction of the target and the direction of the flankers also led to an additional increase in response times, a pattern we have called the walker congruency effect. In this and all figures, error bars indicate one standard error of the mean.
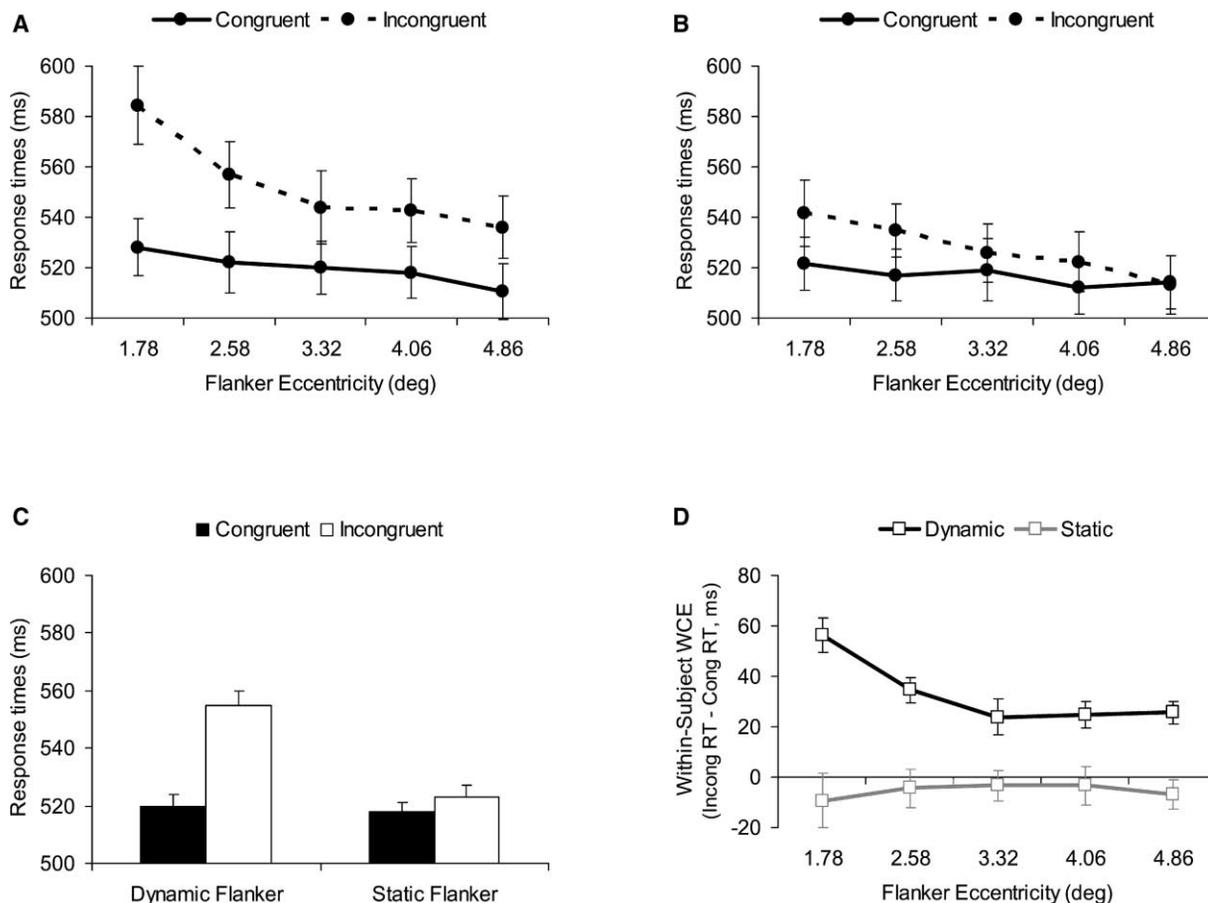
A

B

C

D

Figure 3. Dynamic Not Static WCE across the Visual Field

Response times for dynamic (A) and static (B) flankers from Experiment 2. Panel C illustrates the significant flanker type x congruency interaction. Solid lines/bars represent congruent responses, dashed lines/open bars represent incongruent responses. Panel D summarizes the WCE (incongruent RT – congruent RT) computed separately for each observer. The solid black line represents dynamic flankers, and the solid gray line represents the static flankers. See main text for more details.

Moreover, because all 20 observers showed the same pattern (incongruent > congruent RTs), the magnitude of this cost can be directly calculated from the average RTs shown in Figure 3A (see also Table S3 in the Supplemental Data). For static trials, approximately equal numbers of observers at each eccentricity had an incongruent benefit (congruent > incongruent RT) as had an incongruent cost. The variability in the sign of this effect results in the flat, approximately zero-cost function shown in Figure 3D. Thus, while congruent and incongruent conditions differ for both static and dynamic trials, it is only the latter that gives rise to a consistent WCE.

The results of Experiment 2 rule out a failure to ignore flankers at close proximity as the sole cause of the WCE observed in Experiment 1. It also appears that only dynamic flankers give rise to a consistent WCE. The purpose of Experiment 3 was to explore the possible contribution of the local motion trajectory of individual dots (e.g., wrist or ankle movements) comprising the point-light figures. To test this, we first synthesized normal point-light figures (facing left or right) and then scrambled the initial vertical and horizontal coordinates of individual dots to disrupt the global form of a flanking

figure while preserving the local motion trajectory of right-facing and left-facing figures [24, 26].

Twelve new observers, recruited from the Tübingen community, judged the direction of the central target flanked by either coherent figures or scrambled figures, with the different conditions run in separate blocks of trials. We also varied the display layout, presenting four flanking stimuli in a clockface configuration around the central target figure, as shown in Figure 1B. This was done to ensure that the effects observed in Experiments 1 and 2 did not depend on target and flankers potentially colliding, as would be the case with a linear arrangement.

The median response times for Experiment 3 are shown in Figure 4. Here we tested for the WCE in each condition separately using repeated-measures ANOVAs with target-facing (left, right) and congruency (congruent, incongruent) as within-subjects factors. In the coherent condition, responses to congruent trials (M = 481 ms, SE = 7 ms) were faster than responses to incongruent trials (M = 505 ms, SE = 8 ms) [$F(1,11) = 68.0$, $p < .001$]. Thus, we replicated our previous results with a different configuration and a different number of flanking figures. By comparison, in the scrambled condition, con-
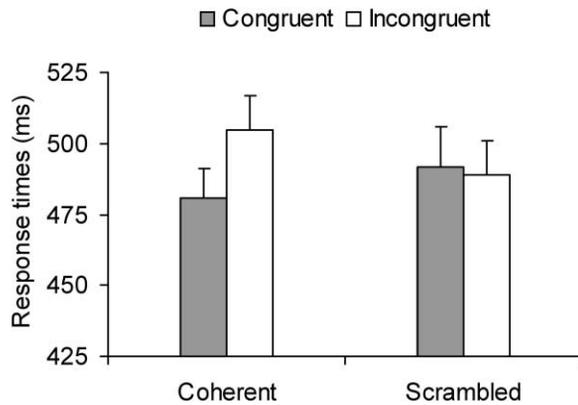
Figure 4. Global Not Local Conflict

In Experiment 3 a WCE was only obtained when flanking figures had a global, coherent structure and movement that conflicted with that of the target. Local, scrambled motion did not lead to a slowing of response times.
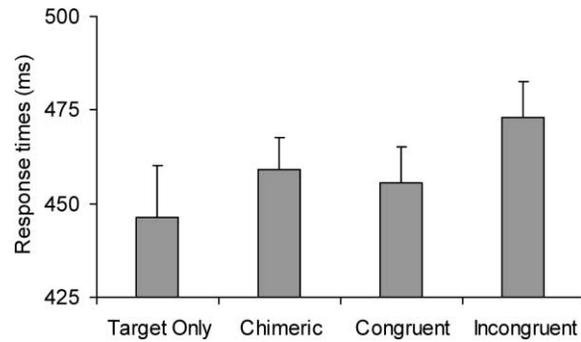

Figure 5. The WCE Is Interference Rather Than Facilitation

In Experiment 4, all flankers led to an increase in response times relative to the target-only condition. As in Experiment 2 the cost of the conflict between the direction of the target and flankers also led to an additional increase in response times. As there was no benefit for congruent trials, compared to the neutral, chimeric trials, it appears that the WCE is primarily a form of interference.

gruency did not influence the speed of responses (M_{Con} = 491 ms, SE = 10 ms; M_{Incon} = 489 ms, SE = 8 ms) [$F(1,11)$ = 0.2, n.s.]. The fact that the scrambled condition showed no evidence of a WCE suggests that it is the global motion of the flanking figures, rather than their individual local motions, that influences responses to the target.

What remains to be seen is whether the WCE reflects interference on incongruent trials, facilitation on congruent trials, or some combination of both. Typical static flanker interference studies address this issue by including "neutral" trials in which flanking items of equal complexity are present but do not map on to any response [6]. Recently, we developed a "chimeric" point-light walker [23], which simultaneously has equal global motion to the left and to the right, making it an ideal neutral stimulus for the current dynamic context. To view a moving version of this stimulus, please see the movie in the Supplemental Data.

In our last experiment, 12 new observers recruited from the Tübingen community judged the direction of the central target in three blocks of trials. In the first block, only the central target was presented. In the second block, the target was always flanked by four chimeric figures in a clockface configuration around the target (see Figure 1B). Finally, observers completed a block of trials with the target flanked by four normal, unambiguous figures, again in the clockface configuration. We used this fixed-block order because we did not want the unambiguous flankers to bias observers' interpretation of the chimeric figure.

The median response times for Experiment 4 are shown in Figure 5. Across the different conditions, we found a pattern of results consistent with interference. A repeated-measures ANOVA with target-facing (left, right) and condition (target-only, chimeric flankers, congruent normal flankers, and incongruent normal flankers), as within-subjects factors, revealed a main effect of condition [$F(3,33)$ = 3.4, p < .05]. Posthoc analysis revealed significant pairwise differences for all comparisons (p < .01), except for that between congruent (M =

459 ms, SE = 6 ms) and chimeric trials (M = 455 ms, SE = 7 ms). In particular, there was both a speed benefit in the target-only condition (M = 446 ms, SE = 10 ms), and a cost in the incongruent condition (M = 473 ms, SE = 7 ms). Thus, while the neutral chimeric condition was indistinguishable from congruent trials, incongruent trials led to significantly slower responses.

The current experiments clearly show that ignored point-light flankers are processed to a level where their global direction is available to compete with responses to a central target. These findings provide the strongest behavioral evidence to date showing that the processing of complex dynamic patterns can be achieved in a passive, bottom-up fashion. In the wild, such processing could clearly be beneficial for the peripheral detection of predators. More speculatively, this apparent "mandatory" processing of biological motion could be exploited by groups of animals in an attempt to confuse an approaching predator. For example, it has been well established that many species follow a simple movement rule in which members of a group move toward their neighbors rather than uniformly in a single direction [27–28]. While the primary motivation for such behavior may well be to use a tightly packed cluster to minimize individual predation risk, the complex, multi-directional movements that result from this rule could also reduce the predator's effectiveness in attacking any single target.

Of course, if humans can adequately process biological motion in a bottom-up fashion, one may wonder why our visual system would also need to employ a range of top-down mechanisms, as have been previously demonstrated [18–23]? One obvious answer may be to cope with situations where low-level motion cues are degraded [3, 22, 24, 26] or ambiguous [23]. More generally, top-down mechanisms may play a crucial role in the selection and interpretation of dynamic patterns so that they can form the basis of an explicit response [20]. In the current work, we have shown that incidentally processed biological motion can indirectly affect responses. It is unclear at present whether observers also have explicit access to these incidentally processed dynamic patterns.

This distinction between implicit and explicit access to dynamic patterns may provide an interesting avenue for reexamining a range of findings relating to neural mechanisms. Recent brain imaging [29–33], neurophysiological [17, 34–35], and neuropsychological [21, 36–38] findings all implicate the crucial involvement of relatively high-level, integrative brain areas. For example, the extent to which the performance of patients with occipito-parietal lesions [38] or the activity of specific regions of interest in fMRI studies with normal subjects [29, 31] are modulated when tasks involve direct versus incidental responses may help shed further light on the nature of biological motion processing.

Conclusions

The current results clearly indicate that biological motion can be processed incidentally. Such a finding has important theoretical implications as it provides the strongest behavioral evidence to date that the processing of such complex dynamic patterns can be achieved in a passive, bottom-up fashion. While similar claims have been made several times before [1–5], these studies typically failed to rule out the possible contributions of more active, top-down processing mechanisms. Our task, on the other hand, excludes many types of top-down processing, because observers are not required to actively interpret the critical aspects of the display.

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