
Active versus passive processing of biological motion

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Abstract. Johansson's point-light walker figures remain one of the most powerful and convincing examples of the role that motion can play in the perception of form (Johansson, 1973 *Perception & Psychophysics* **14** 201–211; 1975 *Scientific American* **232**(6) 76–88). In the current work, we use a dual-task paradigm to explore the role of attention in the processing of such stimuli. In two experiments we find striking differences in the degree to which direction-discrimination performance in point-light walker displays appears to rely on attention. Specifically, we find that performance in displays thought to involve top–down processing, either in time (experiment 1) or space (experiment 2) is adversely affected by dividing attention. In contrast, dividing attention has little effect on performance in displays that allow low-level, bottom–up computations to be carried out. We interpret these results using the active/passive motion distinction introduced by Cavanagh (1991 *Spatial Vision* **5** 303–309).

1 Introduction

Many species, including our own, appear to be highly sensitive to patterns of motion generated by other living organisms (eg Johansson 1973, 1975; Blake 1993; Oram and Perrett 1994; Regolin et al 1999; Yamaguchi and Fujita 1999). Such 'biological-motion processing' can often play an important role in survival. Detection and identification of biological motion can help an animal escape from or avoid dangerous situations, such as the approach of a natural predator or an angry rival. Similarly, it can help to successfully achieve desired contact, during hunting or mating, for example. Given this ecological significance, it seems likely that a visual system might recruit mechanisms at multiple levels in order to provide robust and efficient processing of moving biological objects.

In the current work, we explore the mechanisms that underlie biological-motion processing in the human visual system. In two experiments we use a novel dual-task paradigm in conjunction with more standard temporal (experiment 1) and spatial (experiment 2) display manipulations. Our findings suggest that biological-motion processing in humans can rely on *either* bottom–up or top–down processing mechanisms. Furthermore, we demonstrate that global, top–down mechanisms cannot operate in the absence of attention, whereas more local, bottom–up mechanisms are relatively unaffected by the withdrawal of attention.

The tool most typically used to study biological-motion processing was developed by Gunnar Johansson (Johansson 1973, 1975). Building on earlier work by Marey (1895/1972), Johansson created 'point-light walker' displays by filming human actors with small light sources attached to their major joints. When the contrast of these films

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was adjusted appropriately, all that could be seen were a dozen or so moving points of light. Despite the lack of form information, observers were still able to accurately identify the action being portrayed. These displays remain one of the most powerful and convincing demonstrations of the role that motion can play in the perception of form.

Johansson's stimuli have inspired a great deal of research on biological-motion processing. We now know, for instance, that the ability to process such displays develops within the first few months of life (eg Fox and McDaniel 1982; Bertenthal et al 1985), and that it is a rapid (Johansson 1976), relatively spontaneous (Proffitt et al 1984) process that can be achieved in the presence of fairly complex masking elements (Cutting et al 1988; Bertenthal and Pinto 1994). With point-light walker displays, masking elements typically take the form of additional points of light that are placed around the walking figure and differ only by virtue of motion or grouping characteristics (see figure 1).

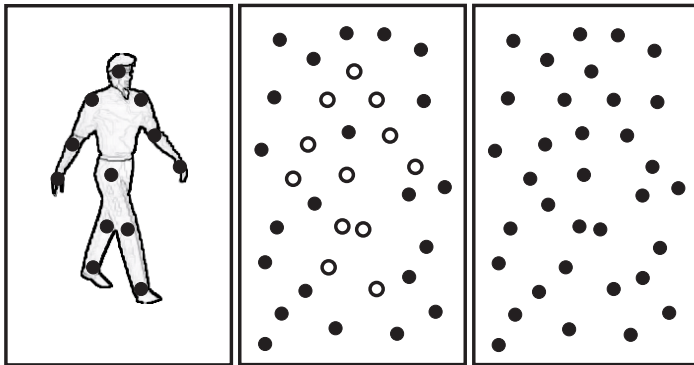


Figure 1. Three static views illustrating the construction of a masked point-light walker display. The outline of the human body, shown in the first frame, is never shown in experimental stimuli. When presented statically, the final displays (third panel) are difficult to interpret. However, when set in motion, observers easily organize the complex patterns of point motion into a coherent perception of human locomotion. In the experimental stimuli, the walker points and mask points are identical, as shown in the third panel.

Johansson began his work on biological-motion processing from within a particular theoretical framework—visual vector analysis—which emphasized the “spontaneous” and “automatic” extraction of “mathematically lawful spatio-temporal relations” in early visual patterns of stimulation (Johansson 1973, 1975). Given this theoretical perspective, it is not very surprising that much early work in this area favored a low-level or bottom-up processing explanation for the perception of biological motion. The fact that naïve observers could quickly and spontaneously identify the events being portrayed, and the success of early bottom-up computational models also lent support to this perspective (Hoffman and Flinchbaugh 1982; Webb and Aggarwal 1982). While there can be little doubt that such low-level motion mechanisms play an important role in biological-motion processing (eg Mather et al 1992), this does not appear to be the whole story.

Specifically, there is now a growing body of behavioral and neurophysiological work indicating that higher-level or top-down processes play an important role in the perception of biological motion. Dittrich (1993) noted that the speed and efficiency of biological-motion processing can be strongly influenced by the category of the depicted action. For example, locomotory actions, such as walking and climbing stairs, are generally recognized faster and more accurately than social actions, such as greeting and dancing. He suggested this difference might reflect the operation of “selective movement filters” that help enhance the recognition of familiar biological motions by

combining knowledge-based, semantic information about human action with observed spatiotemporal movement patterns. Similarly, Cavanagh et al (2001) argue that the human visual system can acquire and use characteristic motion patterns associated with familiar objects and events. Such stored patterns or “sprites” may exert top-down influence during the recognition of familiar dynamic sequences and might be particularly useful when visual input is degraded in some way. More specifically, Cavanagh et al suggest that sprites may play an important role in helping to efficiently predict, track, and mentally animate the motion of familiar objects, such as point-light walkers.

Bertenthal and Pinto (1994) have claimed that the perception of a walker's global form, specified by motion, precedes the perception of individual elements or their local relations. This claim is based on the use of complex masking elements that render individual walker dots or even combinations of dots uninformative. Similar claims for spatially global processing of biological motion have come from studies of aperture-viewed figures (Wallach 1935). Shiffrar et al (1997) found that when observers view a walking-stick figure through multiple apertures, they readily perceive human movement. However, under identical conditions, the perception of non-biological figures (eg scissors or automobiles) always defaults to a local-motion interpretation, suggesting that some internal representation favors a global interpretation for biological stimuli. More recently, Bülthoff et al (1998) provided very compelling evidence for top-down processing of biological motion by showing that depth-order information from disparity cues can be completely overridden when these cues are placed in conflict with the stored dynamic representation of point-light walker motion.

Claims for higher-level or global processing of biological motion have also been made within the temporal domain. Thornton et al (1998) used apparent motion to demonstrate that masked point-light walkers can be accurately perceived across a wide range of ISIs (at least 0–120 ms), well beyond the temporal limits traditionally associated with low-level, local computations of motion (eg Baker and Braddick 1985). Using a slightly different paradigm involving photographs of human limb movements, Shiffrar and Freyd (1990, 1993) and Heptulla Chatterjee et al (1996) demonstrated that biologically plausible paths of motion win out over more direct, biologically impossible paths of motion only when ISIs exceed 200 ms. Such time dependence is consistent with higher-level or top-down influence of stored information about human form interacting with and constraining the interpretation of biological-motion patterns.

Recent neurophysiological research also indicates that relatively high-level, integrative mechanisms may play an important role in the visual analysis of human movement. For example, the superior temporal polysensory area (STP) of the macaque contains cells that respond to precise combinations of primate forms and movements (Perrett et al 1990) and, more specifically, to Johansson point-light figures (Oram and Perrett 1994). Case studies of patients with extrastriate lesions sparing the temporal lobe have also shown that individuals can lose their ability to perceive simple motion displays while retaining the perception of point-light walker displays (Vaina et al 1990; McLeod et al 1996), further implicating some form of high level, top-down processing.

In the current work, our emphasis remains with top-down processing of biological motion. Here we want to suggest that, at least in some situations, this top-down processing takes on a very particular form. Specifically, it is an example of what Cavanagh (1991) has labeled ‘active’ motion processing. That is, in addition to involving high-level, internal representations of the target object or event, this type of motion processing requires ‘cognitive intervention’ at some level, most probably in the form of (re)allocation of visual attention. Active or attentionally modulated motion processing can be contrasted with ‘passive’ motion processing, which is thought to be accomplished

fairly automatically via parallel arrays of motion detectors early in the visual pathway.⁽¹⁾ These two types of processes can be distinguished by the introduction of a demanding secondary task: under some conditions (those in which low-level processes dominate), performance should remain relatively intact, whereas in other conditions (those in which high-level processes dominate), performance should become severely disrupted.

Here we demonstrate just such a dissociation. Specifically, we show that, while traditional point-light walker displays can be processed very accurately even when observers simultaneously perform a demanding secondary task, display manipulations that are thought to involve top-down or global processing of the walking figure, either in time (experiment 1) or space (experiment 2), result in severely reduced dual-task performance. We suggest that this dissociation represents a shift from predominantly low-level and passive to predominantly high-level and active processing of the point-light figures.

2 Experiment 1

Recently it was demonstrated that point-light walker displays can be accurately processed across a wide range of temporal variation (Thornton et al 1998). In these studies, the usually smooth motion of point-light displays was interrupted by inserting blank inter-stimulus intervals (ISIs) between successive walker frames. Such apparent-motion displays have long been used to study the temporal aspects of motion processing (Wertheimer 1912; Korte 1915), and were first introduced to biological-motion processing by Mather et al (1992). Thornton et al (1998) found that, even with ISIs as long as 120 ms, observers were still able to accurately identify direction of motion for point-light figures camouflaged by simple random-dot masks. While there has been much debate about the precise mechanisms that underlie apparent motion (eg Cavanagh and Mather 1989; Petersik 1989, 1991; Cavanagh 1991), successful processing of displays with such long ISIs has typically been thought to require some form of higher-level or global processing (eg Pantle and Petersik 1980; McBeath and Shepard 1989; Shiffrar and Freyd 1990, 1993).

Thornton et al (1998) found that, even though direction-discrimination performance was affected very little by the ISI manipulation, all observers noted a very compelling change in their subjective experience of the walker as smoothness of motion decreased. Specifically, at short ISIs the walking figure essentially 'popped out' of the background mask, while at longer durations walker motion could only be perceived by actively searching for and tracking candidate walker dots. They speculated that this shift in subjective experience might represent differing contributions of passive and active motion processes.

In the current study we present identical stimuli to those used by Thornton et al (1998), but test for a difference in active versus passive motion processing by introducing a second, attentionally demanding task. In all displays, in addition to the point-light walker stimuli, observers were also shown a series of rectangle arrays (see figure 2). These arrays consisted of four items—two horizontally and two vertically oriented

⁽¹⁾ Active versus passive motion processing is usually understood within the context of *motion extraction*—that is, how the visual system is able to register the presence of motion energy. Cavanagh (1991, 1992) suggests that movement of an attentional window could generate active motion signals in the absence of retinal motion. Drawing a parallel to the movement of the eyes, he called this form of motion extraction "covert efference copy" (Helmholtz 1910/1962). Lu and Sperling (1995) suggest that during active motion processing, or third-order motion processing, attention may simply function to select salient features, which are then automatically tracked across time.

Here we suggest the active versus passive distinction can be extended to cover *motion integration* as well as motion extraction. By motion integration we simply refer to the process by which individual features or elements of a complex moving stimulus are combined to give rise to the perception of a unified whole (see Rensink 2000a for a related discussion). This issue is clearly very relevant to the domain of biological processing.

rectangles which were randomly distributed across the whole display area. On half of the trials, one of these rectangles would change orientation between successive views.

In the baseline condition, observers were told to ignore the rectangles and concentrate on locating the walking figure to determine its direction of motion. In the dual-task condition, observers were instructed to monitor the walker and the rectangles. The goal in the change-detection task was to determine whether any one of the four rectangles changed its orientation. This secondary task has been used in studies of change blindness (see Simons and Levin 1997; Rensink 2000c for reviews) and has been shown to require the focal allocation of attention (Rensink 2000b).

Our prediction was simple. If biological-motion processing becomes more dependent on active motion processing as ISI increases, then performance at long ISIs should be greatly affected by the addition of the cognitively demanding rectangle task. Performance with short ISIs, which we have speculated relies more on passive motion processing (Thornton et al 1998), should be much less affected by the addition of the rectangle task.

2.1 Methods

2.1.1 Participants. Three experienced psychophysical observers participated in this experiment. All observers had normal or corrected-to-normal vision. One subject was an author whereas the remaining subjects were naïve with regard to the purpose of this study.

2.1.2 Apparatus. All stimuli were displayed on a Macintosh 21 inch (37 cm × 28 cm) RGB monitor with a refresh rate of 75 Hz and a 1152 × 870 pixel resolution. Monitor output was controlled by a Macintosh Quadra 950. Observers sat some 60 cm from the monitor and the stimuli were presented in a 9.3 deg × 9.3 deg window positioned in the center of the monitor. This apparatus was used in both of the experiments reported here.

2.1.3 Simultaneous displays. Each trial lasted approximately 12 s. During this time, observers were shown displays that simultaneously presented both a point-light walker task and a change-detection task (see figure 2). As described below, the walker task involved determining the direction of a walking figure within a background mask of identical black dots. The change-detection task required monitoring four uniformly colored rectangles to identify if one of them changed orientation between successive presentations. When a change was present (50% of trials), one rectangle rotated by 90° (from vertical to horizontal or the reverse) on each of four successive frames. All displays were presented on a uniform gray background.

2.1.4 Walker stimuli. The walker stimuli were generated by modifying Cutting's classic point-light walker algorithm (Cutting 1978). The animated walking figure was shown in profile and consisted of 11 dots which simulated points of light on the head, near shoulder, both elbows, both wrists, near hip, both knees, and both ankles. As in previous studies (eg Cutting et al 1988; Mather et al 1992; Bertenthal and Pinto 1994) occlusion clues were omitted to avoid providing non-motion cues to direction. That is, dots did not disappear when they normally would have been occluded by the walker's torso or limbs. To increase the difficulty of the task, a masking field of 66 dots was also presented on each animation frame (Cutting et al 1988; Mather et al 1992; Bertenthal and Pinto 1994). The masking dots randomly changed location on each animation frame. As the walker and mask dots were identical, black 9.2 min of arc diameter circles, they could only be distinguished from each other by their motion.

The walker figure subtended 7.2 deg in height (head to ankle) and 3.6 deg in width at the most extended point of the step cycle. A complete stride cycle (ie the sequence of movements that occurs between two consecutive repetitions of a body configuration)

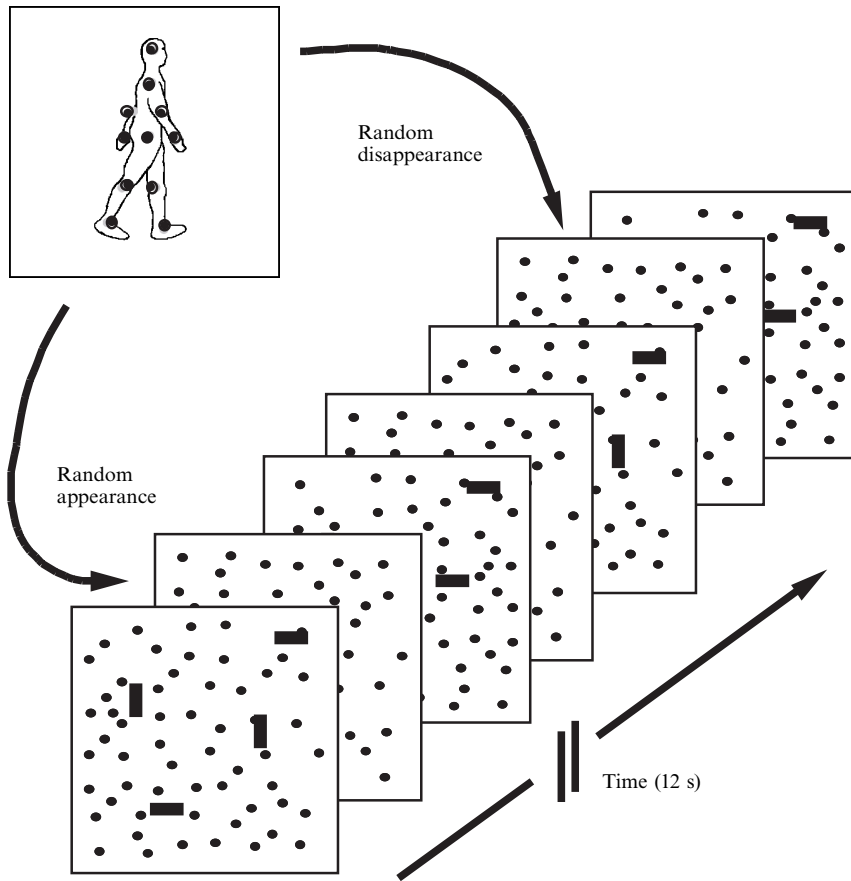


Figure 2. A schematic depiction of a typical trial, showing both masked walker frames and superimposed rectangle stimuli. Each 12 s trial contained four separate sets of rectangles. Across each block, half of the rectangle trials contained a change, half did not. In this example, a change is present, with the bottom right rectangle changing from vertical to horizontal. This trial shows the 0 ISI walker condition, with no blank frames inserted. The onset of the walker was randomized with respect to the start of the trial. The walker disappeared after taking two complete steps. In the experimental stimuli, the walker points and mask points were identical and no outline of the body was present, as described in figure 1.

was achieved in 40 animation frames. The duration of each frame was fixed at 40 ms. As a result, when these frames were presented in immediate succession, a walking speed of 38 strides per minute was simulated, a value well within the range associated with human walking under normal conditions (Inman et al 1981). The walker figure did not translate across the screen but rather appeared to walk in place as if on a treadmill. On half of the trials, the walker faced and walked to the right; while on the other half of the trials, the walker faced and walked to the left. The horizontal and vertical position of the walker within the central display area and the starting position within a stride cycle (eg legs far apart or close together) were randomized on each trial. These display manipulations ensured that subjects would not be able to identify the walker configuration simply by its presentation at a particular location or during a specific animation frame.

To manipulate the ISI, and thereby create apparent-motion displays, a blank frame was inserted between each of the walker animation frames. This blank frame contained no dots and was the same uniform gray as the background in the animation frames.

Across trials, the duration of these blank frames was either 0 ms (no blank frame), 40 ms, or 80 ms.

On each trial the walking figure always completed two full steps (80 frames). Since the number of walker animation frames was fixed but the ISI varied, the total presentation time of the point-light walker sequence in each trial also varied. The walker was presented for 3200 ms in the 0 ms ISI condition (80×40 ms walker frames), 6400 ms in the 40 ms ISI condition (80×40 ms walker frames + 80×40 ms blank frames), and 9600 ms in the 80 ms ISI condition (80×40 ms walker frames + 80×80 ms blank frames). As the overall duration of each trial was 12 800 ms, the onset of the walker display was randomized within this interval (with the restriction that the walker presentation time was shorter than the remaining trial duration). Only the mask and the change-detection task stimuli were presented whenever the walker was not displayed. Walker trials were organized into eight blocks of 15 with each block containing five repetitions of each ISI.

2.1.5 Change-detection stimuli. Each 12 s trial contained four sets of rectangle-change displays. These were superimposed directly on to the walker displays, with each set containing four rectangles measuring 10×30 pixels ($0.31 \text{ deg} \times 0.93 \text{ deg}$). All the rectangles in a given set were drawn in the same color, either green or white, and were oriented either horizontally or vertically. The location of each rectangle was randomized within the main viewing area, with the constraint that it did not approach within 2 deg of the border of the display or another rectangle. The color and screen position of the four rectangles changed for each successive set of rectangles to ensure that observers were aware that a new display was being presented.

Each change displays consisted of four cycles in which the rectangles were visible for 400 ms and then disappeared for 400 ms. On change-present trials, one of the rectangles rotated by 90° around its center during each blank period, thus changing its orientation from horizontal to vertical or vice versa, between successive views. The remaining three rectangles had fixed orientations across all four cycles, as did all of the rectangles in no-change trials. The task of the observers was to report whether one of the rectangles of a set changed its orientation. In each block of 15 walker trials, there were a total of 60 rectangle sets, half of which included a change of orientation. The particular item that rotated on change trials was randomized independently for each set.

2.2 Procedure

Observers were seated in front of the display monitor and were told that on each trial they would see a point-light walker within a mask together with a series of rectangle displays. In separate blocks, observers were given either baseline or dual-task instructions. In baseline blocks, they were instructed to ignore the rectangles and to determine if the walker was facing to the left or right. When the animation was complete, they recorded their response by pressing the 'S' key when the walker appeared to face and walk to the left and the 'K' key when the walker faced and walked to the right.

In dual-task blocks, observers were told to attend to both the rectangles and the walker display. To ensure that observers were attending to the rectangles, they were required to respond "change" or "no change" during each set of four rectangles. That is, they made 4 responses to the different rectangle sets before responding to the walker at the end of the trial. The rectangle responses could be made at any time during the presentation of a set by pressing the 'A' key for change, and the 'L' key for no change. Observers were instructed to focus on maintaining a high level of accuracy on the change-detection task, although no explicit feedback was provided for either the change-detection or the walker task during the experimental sessions. The next trial was initiated by pressing another button on the keyboard.

Each observer completed eight blocks of baseline and eight blocks of dual-task trials. Each block contained 15 walker trials (5 trials at each ISI) and 60 rectangle trials. At least one baseline and one dual-task block was completed in each experimental session, the order of each pair of blocks being randomized independently for each observer. On average, observers completed two blocks of trials in approximately 15 min. The order of the trials within each block was also randomized independently for each observer. All observers completed at least two training blocks of the walker task and the rectangle task under single-task conditions before data collection commenced.

2.3 Results

2.3.1 Walker task. Figure 3 summarizes the point-light walker results for the three observers, under both baseline and the dual-task conditions. When observers ignored the rectangles, performance in the walker task remained close to ceiling across all ISIs ($M = 93\%$, $SE = 1.5\%$). As expected, attending to the rectangle task decreased this performance, the size of the performance decrement changing quite sharply with ISI. When motion was smooth, dual-task performance remained quite high ($M_{\text{dual}} = 85\%$, $SE = 1.1\%$), with a decrease relative to baseline of only 15% ($M_{\text{baseline}} = 100\%$, $SE = 0\%$). However, when the ISI was increased, performance dropped much more sharply both for the 40 ms ISI ($M_{\text{baseline}} = 89\%$, $SE = 5.8\%$; $M_{\text{dual}} = 62\%$, $SE = 4.2\%$) and for the 80 ms ISI ($M_{\text{baseline}} = 90\%$, $SE = 5.8\%$; $M_{\text{dual}} = 58\%$, $SE = 3.8\%$) conditions. These decrements

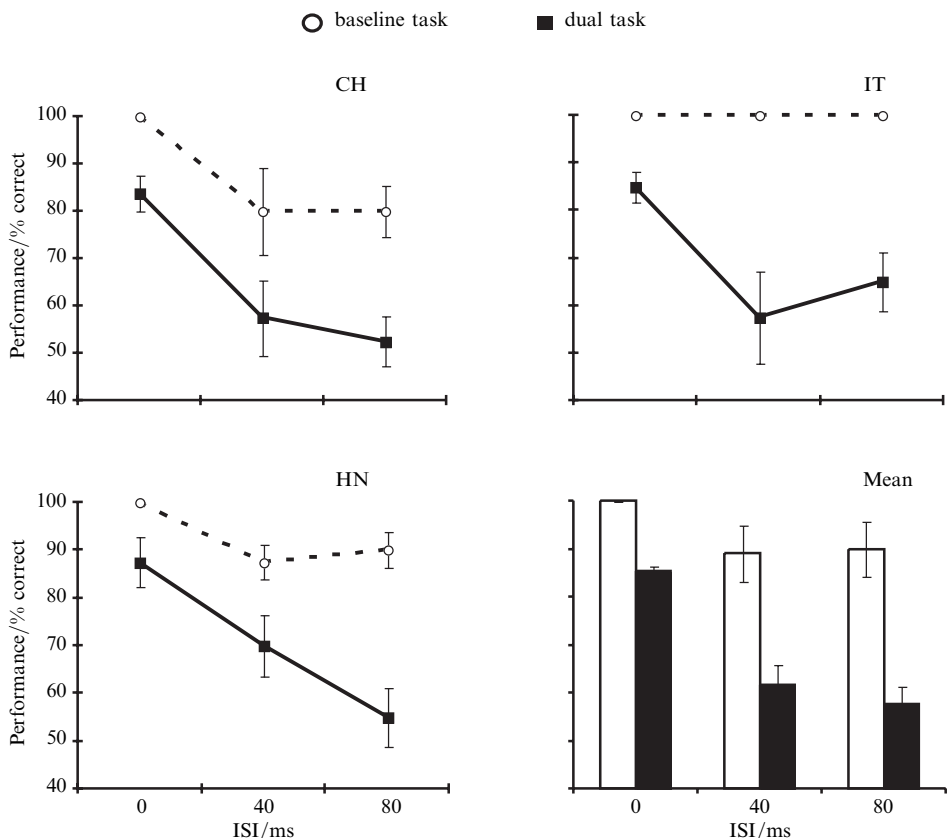


Figure 3. The results of experiment 1. Panels CH, IT, and HN show data for individual observers; the final panel shows mean performance. Performance in the baseline condition (walker task only) is indicated by the filled squares and remains high across variations in the ISI. Direction-discrimination performance drops towards chance levels (50% correct) at long ISIs in the dual-task condition. The error bars represent the standard error of the mean.

represent an increase in error relative to baseline of 27% and 32%, respectively, for the 40 and 80 ms ISIs.

To examine these trends in more detail, the 80 trials for each observer at each ISI level (8 blocks \times 5 baseline trials per ISI + 8 blocks \times 5 dual-task trials per ISI) were split into 8 bins reflecting the separate experimental sessions. These time-series data were then compared in a 2 (Task) \times 3 (ISI) repeated-measures ANOVA. An analysis collapsed across all three observers revealed main effects of both Task ($M_{\text{baseline}} = 93\%$, $SE = 1.5\%$; $M_{\text{dual}} = 68\%$, $SE = 3.6\%$; $F_{1,7} = 43.5$, $MSE = 1.7$, $p < 0.001$) and ISI ($M_0 = 93\%$, $SE = 2.2\%$; $M_{40} = 75\%$, $SE = 5.0\%$; $M_{80} = 74\%$, $SE = 4.7\%$; $F_{2,14} = 16$, $MSE = 1.1$, $p < 0.001$). More importantly, there was a clear Task \times ISI interaction ($F_{2,14} = 4.8$, $MSE = 0.7$, $p < 0.05$; see figure 3, final panel). Separate analysis of the time-series data for each observer revealed an identical pattern of results, with the exception of observer CH, where the Task \times ISI interaction did not reach significance ($F_{2,14} = 0.6$, $MSE = 2.0$, $p = 0.5$). Examination of figure 3 suggests that this lack of interaction is a result of unusually noisy baseline data at the 40 ms ISI.

Finally, performance for the 80 ms ISI under dual-task conditions was compared against the chance level of performance (50%) for each observer. For two observers, performance in this condition could not be distinguished from chance (HN: $M_{80} = 55\%$; $SE = 6.3\%$; CH: $M_{80} = 53\%$, $SE = 5.3\%$; $t_s < 1$, ns). The third observer had small but consistent above-chance performance (IT: $M_{80} = 65\%$, $SE = 6.3$, $t_7 = 2.39$, $p < 0.05$).

2.3.2 Change-detection task. Table 1 summarizes performance on the rectangle task. In general, sensitivity to change was very high, with all three observers maintaining $d' > 2.0$ across the range of ISIs. As change detection of this form is very attentionally demanding, such a pattern strongly suggests that observers were focusing on the rectangle task. As can be seen in table 1, the lowest levels of performance on the change-detection task occurred with an ISI of 0. While a session-by-session analysis showed that the 0 ISI condition was not reliably different from the 40 ms and 80 ms ISI for any observer (all $t_s < 1$, $p_s > 0.5$), the overall pattern is certainly consistent with the subjective reports of observers who felt that the apparent ‘pop-out’ of the walker during 0 ISI trials distracted them from the rectangle task.

Table 1. Experiment 1: Change-detection results.

Observers	ISI/ms		
	0	40	80
IT	4.79	4.81	4.89
CH	3.77	5.72	5.55
HN	2.56	3.48	3.29

Note: Scores show sensitivity to the presence of a change at each level of ISI in terms of d' , a bias-free index defined as follows: $d' = z(H) - z(F)$, where H is the proportion of correct detections, F is the proportion of mistaken detections, and z is the inverse of the normal distribution.

2.4 Discussion

As predicted, the introduction of an attentionally demanding dual task affected direction-discrimination performance in a point-light walker display. Previous work (Thornton et al 1998) had suggested that the perception of biological motion becomes more dependent on active motion processing as ISI increases. Consistent with this suggestion, the current results contain a clear pattern of increasing disruption at longer ISIs, suggesting more reliance on attentional mediation as motion quality decreases.

When the results are examined in more detail, there are at least two interesting patterns that warrant further comment. First, it is clear that, even when motion is relatively smooth (0 ISI), the change-detection task still interferes with biological-motion processing. There is now increasing evidence that almost all visual tasks, including the well-studied ‘pop-out’ phenomenon—long thought to be the hallmark of preattentive processing—can be influenced by the withdrawal of attention (Joseph et al 1997; Rees et al 1997). Thus, the 15% drop in accuracy noted for the 0 ISI condition may not be too surprising. Given this drop, it would not be appropriate to claim that biological motion at any ISI is immune from the effects of attention. The observed pattern of results, however, may reflect differential contributions of passive and active processing across all ISIs.

A second point is that, at least for one of the observers, dual-task performance at the longest ISI is not completely at chance. That is, even with an 80 ms ISI, there is still some ability to process the walking figure. It is possible that some form of passive motion detector could support performance over such time intervals. Had we extended the range of ISIs out to 120 ms, as used by Thornton et al (1998), it seems very likely that all observers would have performed at chance. However, another explanation for this residual performance concerns the shifting of attention. If the rectangle task was not sufficiently demanding, observers may have been able to successfully switch between the two tasks, rather than focusing their attention primarily on the rectangle task. As each rectangle display always remained visible for four cycles, such switching would be feasible if observers were consistently able to spot the orientation change after the first two presentations.

Indeed, as the temporal aspects of the motion-defined walker are very different across the three ISI conditions, briefly switching from the rectangle task to the walker task could yield a pattern of results very similar to those observed here. This follows as the amount of walker information potentially available during a switch would vary considerably depending on the ISI of the animation. For instance, if the switch lasted for 120 ms, this period could contain up to 3 walker frames when the ISI is 0, but only 2 walker frames for the 40 ms ISI and 1 walker frame for the 80 ms ISI condition. If observers were systematically switching between the two tasks, we could thus predict the highest walker performance given smooth motion with moderate to poor performance as ISI increases, simply on the basis of these information differences.

In experiment 2, we address this issue in two ways. First, we substantially increase the demands of the rectangle task by displaying a new set of targets as soon as the observer reports a change. Second, we explore a form of top-down processing in which the motion-defined walker is identical across all conditions.

3 Experiment 2

Bertenthal and Pinto (1994) presented very compelling data to suggest that the perception of biological motion can proceed in a top-down, holistic manner rather than a bottom-up, local manner. They showed that observers could accurately detect the presence of a point-light walker figure that was embedded in a field of complex masking elements. Importantly, the mask was composed of ‘scrambled’ walkers, where each element of the mask exactly mimicked the motion of a single walker point. Such masks are designed to interfere with the perception of the individual features of the walker and to hamper integration processes that might proceed from features and local relations to global structure. Bertenthal and Pinto’s (1994) finding that observers can accurately detect walkers with such complex masks led them to conclude that “the perception of a global form specified by biological motions precedes the perception of the individual elements ...”.

For an experienced observer, the subjective impression of locating a walker in a scrambled mask is very similar to that of locating a walker within the 'random-motion' mask described in experiment 1. That is, the walking figure is quickly and easily located and tracked within the mask. As described below, this subjective impression is supported by comparable performance in baseline conditions, with observers consistently exceeding 90% correct in both mask conditions. In experiment 1, performance with a random mask at 0 ISI was affected very little by the introduction of a demanding secondary task, suggesting that perception of the walker was mediated primarily by a passive process. In the current experiment, we explore the nature of the integration process used during perception of walkers in a scrambled mask. Specifically, is there an automatic, passive mechanism that can provide us with an integrated walker in a scrambled mask, or is the perception of global form mediated by an active integration process?

Despite very similar subjective impressions, there are several reasons to suspect that different processes underlie the perception of walkers in random masks compared with that in scrambled masks. First, in pilot work, we found that naïve and less experienced 'informed' observers found it quite difficult to initially detect a walker in a scrambled mask. Other observers with similar experience never had difficulty in seeing randomly masked walkers. Second, Cutting et al (1988) report that, when total display duration is relatively short (< 800 ms), even experienced observers are at chance at direction discrimination in a scrambled mask. This need for a relatively long integration window argues against a passive, bottom-up process (see also Shiffrar and Freyd 1990, 1993; Shiffrar 1994). Finally, as mentioned above, Bertenthal and Pinto (1994) claim that global, holistic processing is required for processing walkers in scrambled masks. While it is logically possible that such global, holistic processing is accomplished by passive, low-level mechanisms similar to those thought to underlie the processing of randomly masked walkers, it seems more plausible to suggest that this form of biological-motion detection is accomplished with the aid of active, top-down processing (Cavanagh 1992, 1999; Dittrich 1993; Bühlhoff et al 1998; Cavanagh et al 2001).

To explore possible differences between perception of biological motion in random masks and that in scrambled masks, we use the same dual-task logic as in experiment 1. In addition to the masked walking figure, all displays contained a series of change-detection stimuli. As before, these stimuli consisted of arrays of rectangles repeatedly presented, where one of the rectangles could change orientation. As described below, the difficulty of the change-detection task was increased over that used in experiment 1 as we wanted to minimize the possibility that observers could switch back and forth between the two tasks.

By directly comparing direction-discrimination performance with random masks with that with scrambled masks under both single-task and dual-task conditions, our aim was to more fully assess the role of attention in the perception of human locomotion. The scrambled/random manipulation is particularly appealing in this regard because the target (ie the motion-defined walker) is identical in all conditions. In experiment 1, the quality of motion for the whole display was varied, and thus the nature of the target item was not held constant. Here, only the mask changes, and with it the relative efficiency of integration strategies. Specifically, when a point-light walker is presented within a mask of positionally scrambled walkers, only a global, holistic integration strategy will support fast and efficient target identification. On the other hand, both local and global integration strategies can be used in the identification of a walker displayed within a random-motion mask since the motion of each of the masking elements differs from the motions of each element defining the walker.

Our hypothesis is that global integration strategies proceed in a top-down fashion, and, more specifically, that they are an example of active motion processing in that they require the intervention of attention. Local integration strategies could well proceed

in a bottom–up manner and may be subserved by passive, automatic motion processes. Our main prediction is thus that performance should only be significantly affected by the introduction of a dual task in the scrambled-mask condition.

3.1 Method

3.1.1 *Participants.* Six experienced psychophysical observers participated in this experiment. All observers had normal or corrected-to-normal vision. One observer was an author and two other observers had participated in experiment 1. With the exception of the author, all observers were naïve with regard to the purpose of this study.

3.1.2 *Simultaneous displays.* The basic stimulus parameters, procedures, and trial organization were identical to those of experiment 1. That is, on each trial observers were simultaneously presented with a masked walker and a series of change-detection trials. However, trial duration was considerably shorter (6400 ms) as smooth motion (ie no blank ISIs) was used throughout. Also, the difficulty of the change-detection task was increased so that sets of rectangles only flickered once instead of twice. These changes are more fully described below.

3.1.3 *Walker stimuli.* The point-light walker display was identical to that used in experiment 1 except that (a) the ISI was always 0, thereby generating smooth apparent motion during all trials, and (b) in separate blocks, the motion of the masking elements was varied. In one half of the blocks, the simple, random mask used in experiment 1 was presented. In the other blocks, a more complex, ‘scrambled walker’ mask was used. In these more complex masks each dot had a motion trajectory that was identical to the trajectory of one of the dots defining the walker. The mask was created by generating six copies of the walker within the display area. The initial vertical and horizontal positions of each dot were then randomized within the display window. As a result, each mask dot had the same velocity as one of the walker dots but bore no predictable spatial relationship to any other dot. For both types of mask, the dots were always the same size, color, and luminance as the walker dots. The walker always took two strides which were completed in 3200 ms. The onset of the walker was randomly positioned with the first half of the 6400 ms trial duration.

3.1.4 *Change stimuli.* While the basic change-detection display and task remained the same, there were three important changes. First, each set of rectangles was only presented at most for two on–off cycles (1600 ms). In experiment 1, four cycles (3200 ms) had been used. This reduced duration greatly increased the difficulty of the change detection. Second, all potential delays between an observer’s response to the current set of rectangles and the onset of the next set of rectangles were eliminated. In experiment 1, each set of rectangles was always presented for the full four cycles. While observers were free to report an orientation change as soon as they detected one, their responses did not arrest the presentation of that particular set of rectangles. As a result, rapid responses gave observers time to switch their attention to the walker display. In this experiment, an observer’s change-detection response to a given set of rectangles immediately prompted the onset of the subsequent set of rectangles. This made it virtually impossible for observers to switch their attention to the walker. This modification also meant that observers saw between four and six sets of rectangles per walker trial, depending on the speed of their responses. Finally, we switched the response mode from the 2AFC keypress procedure used in experiment 1 to a go/no-go keypress procedure. Pilot testing suggested that a 2AFC procedure, where a keypress was required for each rectangle display, was too demanding, given the overall increase in the rectangle presentation rate.

3.2 Procedure

All observers were given training in both the walker and the rectangle tasks to ensure that they could discriminate walker direction and orientation change under optimal conditions. They then completed four baseline blocks (4×10 walker trials) and four dual-task blocks (4×10 walker trials) for each type of mask. Block order was randomized on an observer-by-observer basis.

3.3 Results

3.3.1 Walker task. The main finding of experiment 2 is shown in figure 4. Baseline performance for both the random ($M = 98\%$, $SE = 1.0\%$) and scrambled ($M = 91\%$, $SE = 2.0\%$) mask conditions was very high. However, while attending to the rectangle task had very little impact on direction-discrimination performance for the random mask, in the scrambled-mask condition performance dropped to chance ($M = 52.9\%$, $SE = 2.7\%$, $t > 1$). Data were analyzed with a 2 (mask) \times 2 (task) ANOVA with block as a repeated measure. This analysis revealed a main effect of mask ($F_{1,5} = 217.8$, $MSE = 46.88$, $p < 0.001$), with random masks ($M = 93\%$, $SE = 1.7\%$) leading to higher performance than scrambled masks ($M = 72\%$, $SE = 3.2\%$); and task ($F_{1,5} = 215.2$, $MSE = 68.5$, $p < 0.001$), with baseline performance ($M = 95\%$, $SE = 1.2\%$) exceeding dual-task conditions ($M = 70\%$, $SE = 3.1\%$). More importantly, the mask \times task interaction shown in figure 4 was also highly reliable ($F_{1,5} = 16.7$, $MSE = 263.5$, $p < 0.01$). A posteriori analysis of this interaction indicated that performance in both the scrambled ($t_5 = 12.76$, $p < 0.0001$) and the random ($t_5 = 2.6$, $p < 0.05$) mask conditions was affected by the task manipulation, although, clearly, the magnitude of the effect is much larger in the scrambled case.

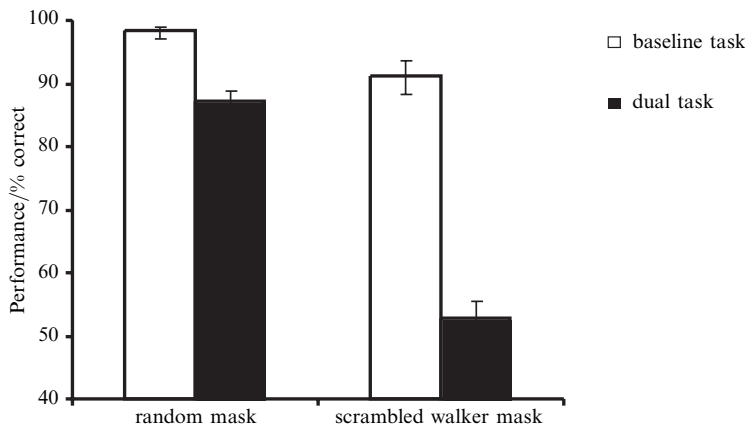


Figure 4. The results of experiment 2 collapsed across observers. Performance in the baseline direction-discrimination condition (open bars) remained relatively high for both the random and scrambled masks. Filled bars show direction-discrimination performance under dual-task conditions. Performance is particularly disrupted in the scrambled-mask conditions. Error bars represent the standard error of the mean, chance performance is 50% correct.

3.3.2 Change-detection task. Table 2 summarizes performance on the rectangle change-detection task. In general, sensitivity to change was again very good, with only one observer having $d' < 2.0$ in both conditions. A comparison with table 1 suggests that we were successful in making the rectangle task relatively more demanding, as change-sensitivity scores are slightly lower than in experiment 1. However, in absolute terms, they are still high, suggesting that observers were still focusing predominantly on the rectangle task. As can be seen in table 2, there was a general trend for sensitivity to change to be slightly better during scrambled-mask blocks ($M = 2.8$, $SE = 0.2$) than random mask ($M = 2.5$, $SE = 0.2$). While this pattern appears in the data for five of

Table 2. Experiment 2: Change-detection results.

Observers	Mask		Observers	Mask	
	random	scrambled		random	scrambled
CH	1.73	1.96	IT	2.59	2.79
AY	2.97	3.60	RS	2.75	3.17
AR	2.38	2.67	HN	2.80	2.48

Note: Scores show sensitivity to the presence of a change at each level of ISI in terms of d' .

the six observers, analysis revealed only a very marginal trend ($t_5 = 1.87$, $p = 0.12$). Nevertheless, this overall pattern is consistent with the idea that the more compelling percept of the walker during random trials could have interfered with change detection to a greater extent than during scrambled-mask trials.

3.4 Discussion

As predicted, under dual-task conditions, performance in a direction-discrimination task was severely disrupted only when the walking figure was presented in a scrambled mask. This finding is consistent with the hypothesis that top-down, active motion processing is required to accurately process the walking figure in this type of mask and, hence, to perform global-motion analyses of human locomotion. The contrast between single-task (91%) and dual-task (52%) performance in the scrambled-mask condition is particularly striking, suggesting an almost complete reliance on active motion processing. As mentioned in the introduction, most experienced observers who view a walking figure in a scrambled mask report that the walker is located and tracked with relatively little effort and/or delay. The baseline performance and the subjective impression both suggest that active motion processing can be a very effective mediator of biological-motion processing.

While withdrawal of attention did not appear to severely disrupt processing in random-mask conditions, it did, nevertheless, have some impact. As in experiment 1, there was a slight drop in performance to around 87%. This drop may simply reflect interference from the second task on memory for the direction of the walker (as this response was made at the end of the trial) or upon left/right response selection, rather than on motion processing itself. However, on the basis of the current evidence, it appears that all forms of biological-motion processing show some sensitivity to the withdrawal of attention (Joseph et al 1997; Cavanagh et al 2001).

4 General discussion

In two experiments, we introduced a dual-task methodology to the study of biological motion. Our findings indicate a striking difference in the degree to which performance on some forms of point-light walker displays appears to rely on attention. Specifically, we found that displays thought to involve top-down processing, either in time (experiment 1) or space (experiment 2), depend to a large extent on the availability of attention. When attention is focused elsewhere—in this case on a simplified change-detection task—biological-motion processing appears to fail almost completely. That is, performance in both experiments was at or near chance under dual-task conditions for displays thought to involve top-down processing. Interestingly, while biological-motion processing remained relatively intact for conditions involving smooth walker motion in random masks—conditions thought to favor passive, bottom-up processing—there was still some effect of dividing attention. This suggests that attention may always play some role in helping to process, or at least to interpret, 'standard' biological-motion displays (Cavanagh et al 2001).

Bearing this general sensitivity to attention in mind, we should also acknowledge that, while the current findings are clearly consistent with a qualitative distinction between top-down, active processes and bottom-up, passive processes, dual-task decrements *alone* cannot provide the final word on this issue. Almost any form of visual processing, including prototypical 'low-level' phenomenon such as pop-out (Joseph et al 1997; Rees et al 1997) and luminance-based motion processing (O'Craven et al 1997; Raymond et al 1998) will show some sensitivity to the withdrawal of attention. Our approach in this paper, however, has been to take display manipulations previously implicated—either on empirical or theoretical grounds—in top-down or bottom-up processing, and to test for differential dual-task sensitivity: 'top-down' displays should be much more susceptible to the withdrawal of attention than 'bottom-up' displays. The pattern of diverging sensitivity found in the two studies reported here clearly matches this prediction. Furthermore, the absolute level of dual-task decrements observed with the putative 'top-down' displays (ie almost complete failure of biological-motion processing) shows a reliance on attention which is at odds with the generally accepted notion of a low-level, bottom-up system. Therefore, we believe the current findings provide important converging evidence for the existence of separate top-down and bottom-up routes for the processing of biological motion.

The current findings would also seem to provide further support for Cavanagh's (1991) general distinction between passive and active motion processing. Here we employed a dual-task paradigm to explore the contribution of attention, rather than designing stimuli that specifically excluded passive motion processing (eg Cavanagh 1992; Lu and Sperling 1995). The results of both experiments lend weight to the idea that some forms of motion processing rely on the availability of attentional resources. We also shifted the emphasis from motion extraction to motion integration. In experiment 2, the target motion was identical in all conditions and all that varied was the ease with which the individual walker elements could be integrated into a unified whole. The results of this experiment clearly suggest that integration strategies needing to operate in a global, top-down fashion are attention dependent.

As a contribution to studies of biological motion, we believe the current work makes two important points. First, it adds to our understanding of what it means to process biological motion in a top-down fashion. As mentioned in the introduction, evidence from a large range of sources pointed to significant top-down influences on biological motion (eg Dittrich 1993; Berenthal and Pinto 1994; Oram and Perrett 1994; Heptulla Chatterjee et al 1996; Bühlhoff et al 1998; Thornton et al 1998). While this work shares a common assumption that 'top-down' involves some form of stored, possibly dynamic, representation, the current findings suggest that such representations require attention if they are to be successfully deployed. Our findings lend support to Cavanagh's suggestion that the visual system may employ special-purpose 'visual routines' (Ullman 1984) or 'sprites' as a means to process the motion of familiar objects (Cavanagh 1999; Cavanagh et al 2001). Future studies will be needed to determine whether attention plays such a vital role in all forms of 'top-down' biological processing (eg Bühlhoff et al 1998).

Second, the current work reinforces the notion that biological-motion perception is highly robust. Fast and accurate processing of potential predator and/or prey is clearly highly adaptive. The current work demonstrates that the human visual system can provide such efficient processing via at least two separate routes—a passive, automatic system that is affected only slightly by the withdrawal of attention (baseline, random-mask performance, experiments 1 and 2), and a top-down, active system that is much more dependent on the availability of attentional resources (80 ms ISI, experiment 1; scrambled mask, experiment 2).

We are not suggesting that the use of both passive and active motion processing is unique to biological motion. It seems likely that in processing most types of motion display we have access to both systems. Except under very specific experimental conditions, the end result of motion processing most probably always reflects some combination of these two systems. However, it is possible that the perception of biological motion draws on active and passive processing in a highly unique and efficient way—allowing us to perceive very similar final percepts via very different mechanisms. It remains to be seen whether such efficiency is obtainable with other, non-biological stimuli.

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