Spatial Vision, Vol. 5, No. 4, pp. 303–309 (1991)

Short-range vs Long-range motion: Not a valid distinction

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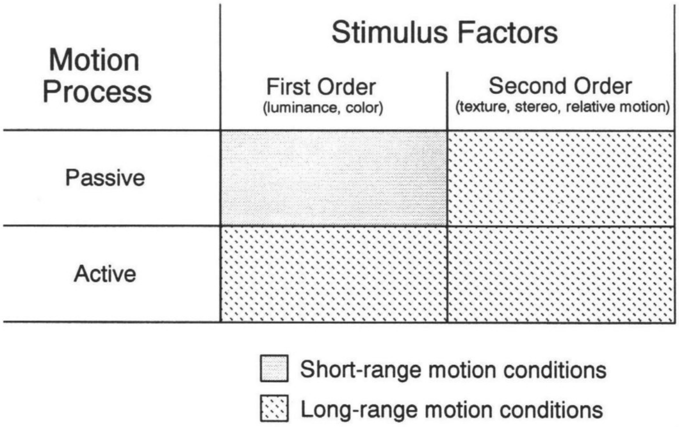
Received and accepted 10 April 1991

In our previous article (Cavanagh and Mather, 1989), we claimed that the reported differences between short-range and long-range motion phenomena are a direct consequence of the stimuli used in the two paradigms and are not evidence for the existence of two qualitatively different motion processes. In his comments, Petersik (1991) argues that although the distinctions between short- and long-range motion are fuzzier than originally claimed, the two motion processes remain a legitimate classification.

In response, I will first outline a logical flaw in the short-range versus long-range distinction. This flaw applies only to the strong version of the distinction, but those reading the motion literature for the first time will probably come away remembering only this version, so its flaws deserve scrutiny. I will then describe two factors that are necessary to understand motion phenomena, one a stimulus factor and the second a process factor (Fig. 1). 'Short-range' and 'long-range' phenomena can be mapped onto this 2 × 2 structure showing clearly that the previous classification confounded stimulus and process dimensions. Finally, I will comment on the group- vs element-motion paradigm (Ternus display) that Petersik uses to support his claims for short- and long-range motion processes.

First of all, the strong version of the short-range vs long-range distinction is stimulus based: that is, one type of stimulus (e.g., small elements moving short distances) activates the short-range motion process whereas a second type of stimulus (e.g., large elements moving large distances) activates the long-range motion process. These two stimulus classes are mutually exclusive so that, at least locally, any given stimulus can activate only one or the other process (Petersik, 1989, p. 109). Not all researchers share this viewpoint, but it is encouraged by the nature of the short-range, long-range distinction.

The problem with a stimulus-based classification such as this one is that it creates a logical dead-end. The many performance differences reported in the literature for different motion stimuli could be attributed either to separate motion processes engaged by the different stimuli or to one motion process whose performance is affected by stimulus properties (e.g., contrast, spatial, and temporal frequencies). How to decide? The basic strategy required to demonstrate that there are two separate processes is the same one that Lois Lane uses to test whether Clark Kent and Superman are really two different individuals: both of them have to be seen at the same place and the same time. However, since different stimuli are required to engage the short- and long-range motion processes, they can *never* be both engaged for the same stimulus (here I mean one simple stimulus, not different parts of a complex



Motion Process	Stimulus Factors: First Order (luminance, color)	Stimulus Factors: Second Order (texture, stereo, relative motion)
Passive	▒	▨
Active	▨	▨

▒ Short-range motion conditions

▨ Long-range motion conditions

Figure 1. Two factors in motion perception. A stimulus factor divides stimulus types into first-order or second-order. First-order stimuli (luminance or color) can be defined at a single point. Second-order stimuli require two points, separated in space for texture, separated by eye for binocular disparity, and separated by space and time for motion. Two types of motion processes—active and passive—can respond to both of these stimulus types. Passive motion processes involve dense arrays of localized motion detectors that monitor all areas of the retina. Active processes involve tracking individual targets with attention as they move about the visual field. These two factors produce four possible combinations. Short-range motion, as originally described by Anstis (1980) and Braddick (1980), corresponds only to the responses of passive motion processes to luminance stimuli. Long-range motion corresponds to the remaining three combinations.

stimulus). Because of the way the motion processes are defined in the strong version, we can never test them for independence. On the other hand, if we apply our coexistence test and find evidence of two systems that can be activated by the same stimulus, then any stimulus-based distinction between the two systems, such as the strong version of the short-range versus long-range classification, is automatically invalidated. I will provide evidence of coexistence in the second section.

My argument is therefore not against two motion systems, but against a stimulus-based distinction between motion processes. The particular names used in the short-range vs long-range distinction have already been shown to be inappropriate for the spatial and temporal ranges over which the original stimuli produce motion impressions. The motion of ‘short-range stimuli’ (kinematograms) can be seen for large displacements (up to 4 deg, Bischof and Di Lollo, 1990), and the motion of ‘long-range stimuli’ such as stereo-defined shapes (Anstis, 1980) is visible over short displacements (for example, when the corrugations in a dynamic random-dot stereogram are seen to drift at a slow speed). The problem lies not just with the names of the motion processes, however, but with the nature of the distinction labeled by the names. We need to advance beyond a stimulus-based distinction and base the classifications of motion systems on the nature of the mechanisms that are involved.

In our previous paper, we rejected the short-range vs long-range distinction as inappropriate and suggested that first-order vs second-order was a more representative classification of the *stimuli* that produce motion impressions. The difference between first- and second-order motion lies in the stimuli and the sensors that respond to the stimuli, but not in the motion analysis. We propose that a single style of motion analysis, similar to the well-known Reichardt (1961), Marr-Ullman (1981) or Adelson and Bergen (1985) motion detectors, underlies motion responses to both classes of stimuli. In this note, I will add a second dimension to the previous one, a process dimension that contrasts passive motion detection to active motion detection.

PASSIVE AND ACTIVE MOTION PROCESSES

Low-level motion detection is assumed to be based on the responses of dense arrays of motion detectors arranged so that each retinal location is monitored by a set of detectors tuned to different directions of motion and different scales of stimulus size. We argued previously (Cavanagh and Mather, 1989) that several arrays of detectors are present that are capable of responding to the motion of stimulus contours defined by luminance, stereo, texture, motion, and color. Note that although some of these stimulus types were considered (Anstis, 1980; Braddick, 1980) to be short-range motion stimuli (e.g., luminance) and others long-range (e.g., stereo or texture), we proposed that the same passive style of motion processing was available for all these stimulus types.

In contrast, a second style of motion processing might be called active motion perception because it involved the use of attention to track moving stimuli. Unlike tracking with eye movements, it appears that attention can track several independently moving targets simultaneously (Pylyshyn and Storm, 1988) although probably not more than 4 or 5 at once. This implies that active motion processes can follow only a few items, a very different capacity from that of the large number of passive detectors each monitoring an individual region of the visual field. In addition to the difference in capacity, there is a difference in style. The tracking mechanism is object-specific (see Kahneman *et al.*, 1991), dedicated to a given target and able to process that one target as it continues to move about the visual field. Unlike the passive motion detectors, it is not attached to any specific retinal location.

If the tracking mechanism merely selected a motion signal from the passive motion detectors activated by the moving object, then it would not constitute a separate motion process. However, I have presented evidence (Cavanagh, 1990, 1991, details below) that when stimuli are tracked with attention, the impression of motion is derived from the signals that move the attention window, independently of the signals produced by passive motion detectors within the window. In this sense, the perception of motion for objects tracked with attention is similar to the motion perceived for smooth pursuit targets. During pursuit eye movements, the target has little or no motion on the retina and so produces no motion signal from the arrays of passive detectors. It is perceived to move, however, and according to Helmholtz's (1910) theory of efference copy, the impression of motion is derived from the signals that control the movements of the eyes. In the case of a target tracked with attention, we might use the term 'covert efference copy' for the process that produces the impressions of motion.

This attention-based motion process can obviously respond to the same stimuli that activate the passive detectors (although there may be some differences in sensitivity). This distinction is therefore independent of the stimuli present in the display. Any given stimulus may engage either or both passive and active motion mechanisms and the observed performance can only be interpreted meaningfully if it is known which are involved. Figure 1 gives a schematic view of the possible combinations of first- and second-order stimuli with passive and active mechanisms, as well as an overlay to show which combinations were considered short-range and which long-range in the classifications presented by other authors.

Having defined two motion processes—active and passive—that are not linked to specific stimuli, we are now free to verify whether these are independent processes by finding a single stimulus which actives both of them. This is trivially true for a simple stimulus involving only a few elements such as a single moving disk (1 element) or a motion competition display (2 elements). These simple stimuli generate responses from the arrays of passive motion detectors and they undoubtedly also engage attention in actively tracking the small number of moving elements. Any performance measured with these simple stimuli is therefore likely to confound the two processes and does not offer an interpretable result for either. In these simple stimuli, both processes signal the same direction of motion. The possibility that two signals are contributing to a common impression of motion has important consequences for our interpretation of the perceived motion, but it does not constitute proof that there are two separate processes. To provide such proof, we must show that there are individual stimuli for which the two processes produce *different* impressions of direction or speed. On this point, Petersik (1989, 1991) and I are in complete agreement since he relies on the Ternus display to support the coexistence of short- and long-range processes. He claims that this stimulus activates both short- and long-range motion processes but his interpretation is challenged by some recent data. The Ternus stimulus will be considered in more detail in a later section.

The first demonstration of the coexistence of active and passive motion processes involves counter-rotating gratings (Cavanagh, 1990). A radial grating defined by sinusoidal variations in color was superimposed on a similar grating defined by sinusoidal variations in luminance and the two gratings were set in rotation in opposite directions. When the contrast of the luminance grating was low, the combined stimulus appeared to rotate in the direction of the color grating. When the contrast of the luminance grating was increased above about 10%, the stimulus appeared to rotate as a whole in the direction of the luminance grating. However, if the observer (while fixating the center of the radial stimulus) then attended to individual colored spokes, the tracked spokes were easily seen to move in the direction opposite to that of the overall rotation. On the other hand, observers could not track the luminance spokes (either with attention or with eye movements) even though these features produced the visible overall rotation of the stimulus! The reason that the luminance bars could not be tracked seemed clear enough: They could not be seen. They were above their threshold for producing motion but at, or below, their threshold for visibility. A superimposed chromatic stimulus raises the pattern threshold for the luminance bars (De Valois and Switkes, 1983) but apparently not the motion threshold.

This dissociation between the direction seen for the overall motion and the direction in which individual bars could be tracked shows that tracking cannot be based on the motion signals from passive, or low-level detectors, otherwise the luminance bars that were producing the dominant motion signal could have been tracked at least as easily as the color bars. This result indicates that there must be two independent sources for the impressions of motion available in this stimulus: one for the judgement of overall rotation (passive) and a separate one for the tracking (active). Evidently, luminance and color features must make very different contributions to these processes. The luminance bars contribute strongly to the perception of global rotation even though, in the presence of the color grating, they are barely visible; the color bars only contribute weakly to the overall rotation even though they are highly visible. In addition, the results indicate that in order for a pattern to be tracked, it must be visible. Thus the high visibility of the color stimulus enabled robust tracking and clear motion impressions for individual spokes even in the direction opposite to the overall motion while the virtual invisibility of the luminance patterns made them difficult to track.

The differential sensitivities of the two motion processes were also revealed in a study of a rotating grating made up only of colored spokes (Cavanagh, 1991). When the colors were equiluminous and no particular attention was paid to the individual features of the rotating grating, the apparent rate of rotation was slower than its true rate (Moreland, 1982; Cavanagh *et al.*, 1984). However, when observers were instructed to attend to individual spokes of the grating while fixating the center of the annulus, the tracked features were judged to move at their true speed. In this case, the participation of two motion processes for the same stimulus is evident through their different sensitivities to chromatic motion, the passive system showing a significant loss whereas the active system was unimpaired.

The purpose of this note is not to catalog the properties of the active motion mechanism that I am proposing nor to determine how it derives its motion signal but only to suggest that it exists and that its presence needs to be considered when results for different motion experiments are compared or interpreted. Most important, it is an independent mechanism for sensing motion that can operate in parallel with passive motion detectors and probably most often does. As argued above, the active and passive mechanisms pass the test for independent mechanisms while strong versions of stimulus-based, short- vs long-range classifications *can never do so.* Figure 1 outlines the links between previous classifications and the new 2 × 2 classification. This classification does not present any new properties of motion perception but reorganizes the phenomena into stimulus and process dimensions. The previous distinction confounded these two, with the result that the effects of the stimuli were often attributed to the capacities of the processes.

GROUP vs ELEMENT MOTION DISPLAYS

Petersik (1989, 1991) often relies on the Ternus display to argue for the distinction between short- and long-range processes. In the Ternus display, three disks are presented in the first frame and alternate with three disks in the second frame. Two of the disks remain at the same location in both frames. When the interstimulus interval (ISI) between the two frames is greater than about 50 ms, the three disks are seen to move as a group (group motion). When the ISI is less than 50 ms, the two central disks appear to remain in place while the outer disk jumps back and forth over them (element motion). Petersik and his colleagues (Pantle and Picciano, 1976; Petersik and Pantle, 1979; Pantle and Petersik, 1980; Petersik, 1989) have claimed that the two motion percepts provide support for the existence of two motion processes. According to these authors, element motion is controlled by short-range processes and group motion by long-range processes.

A recent paper by Patterson *et al.* (1991) calls this into question. They presented the Ternus display as a dynamic, random-dot stereogram and found the same relation between ISI and the perception of group or element motion as when the stimulus was defined by luminance. There are two possible interpretations of these results and neither of them supports the short-range vs long-range distinction.

First, two motion processes may be involved but both of them must be capable of responding to stero-defined stimuli. Traditionally, short-range motion processes cannot respond to stereo-defined stimuli (Anstis, 1980; Braddick, 1980). Thus, if the Ternus display is taken as evidence for the coexistence of two motion processes, the two processes cannot correspond to the traditional short-range and long-range mechanisms. Alternatively, two motion processes may not be necessary to explain the two organizations of the Ternus display. The bistability of many motion displays (Ullman, 1979; Ramachandran and Anstis, 1986) can be understood without invoking two motion processes. Small changes in the stimulus arrangement can tip the most likely mapping of nearest neighbors into very different configurations (Ullman, 1979). In either case, the Ternus display does not support the traditional distinction between short-range processes and the interpretation of the bistability of the display (Petersik, 1989, 1991) needs to be re-examined.

CONCLUSIONS

The short-range vs long-range distinction is stimulus-based and does not capture the likely case that two motion processes may respond to one stimulus. The short-range and long-range labels themselves are not appropriate for the known performance with the original stimuli. A better stimulus distinction is between first-order and second-order stimuli. These two classes are easy to define and also seem to correspond to real differences in sensors in the visual system.

These stimulus-level distinctions do not tell us about motion mechanisms, however. For that we need to use process distinctions. Active and passive are the two processing styles that I have suggested here with passive processes refer-ring to a dense array of localized detectors each specialized for a particular direction, spatial scale and stimulus type (Cavanagh and Mather, 1989). Active processes refer to object tracking operations available for following objects with attention (Treisman, 1986; Pylyshyn and Storm, 1988; Kahneman *et al.*, 1991). Only a few independent processes of this type appear to be available but each can be attached to a particular object and continue to process it as it moves around the visual field.

The first-order vs second-order distinction between stimuli is valid for both types of motion processes. Different first- or second-order sensors are used to feed information into the passive motion detectors and, in a similar manner, different sensors (first- or second-order) can support the shape-extraction processes that identify the object for active tracking.

The group vs element paradigm that Petersik has used to support most of his arguments is not a compelling choice. Recent evidence shows that the same dependence on timing parameters also shows up in a cyclopean version of the stimulus (Patterson *et al.*, 1991), a clear refutation of the role of putative short-range motion processes in the phenomenon.

In summary, it is time to retire the short-range vs long-range labels: they are inappropriate and they confound variation along two different dimensions: stimulus and process.

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