Reports

Parallel and Serial Processes in Motion Detection

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Apparent motion was used to explore humans' ability to perceive the direction of motion in the visual field. A marked qualitative difference in this ability was found between short- and long-range motion. For short-range motion, the detection of the direction of motion is characterized by parallel operation over a wide visual field (that is, detection performance is independent of the number of objects in an array). When the positional displacement is large relative to an object's size, the direction of motion is detected in a serial manner. The process of detection is limited in this case by the ability to detect other events, such as appearance and disappearance of an object, and the ability to compute their spatio-temporal relations. The results are consistent with a previously suggested division of the motion detection system into short- and long-range processes. The direction of short-range motion can be perceived in parallel (preattentively), whereas long-range motion is attentive and requires more complicated computations. It seems that the detection of long-range motion is a conjunction task, combining the detection of disappearance and appearance.

An examination of the conditions under which apparent motion can be perceived has suggested that two processes are involved in producing the perception of motion (*1*). One process, short-range (SR) motion, operates when the spatial and temporal offsets are small. The other process, long-range (LR) motion, can operate over large displacements. It was suggested (*2*), however, that there is a more fundamental distinction between the two systems. The SR process seems to operate directly on changes in the local density distribution. In contrast, the LR process operates by first identifying image features and then matching them over time. We now show that the dichotomy of SR and LR processes is related to another dichotomy in vision, namely, between preattentive and attentive vision.

It has been suggested (*3, 4*) that vision operates in two modes. The first, preattentive vision, is such that feature differences can be detected in parallel over a wide visual field. The second, the attentive mode, is required for detecting more complicated characteristics of objects, such as feature conjunctions (*3*), their spatial relations (*4*), or feature identification (*5*). Such tasks can be accomplished only by the serial shifting of an "attentive aperture" over small parts of the visual field.

Others have shown that direction of motion can be extracted by parallel processes (*6*) for small displacements (SR). We find that, when the displacement increases and motion detectability remains the same, the detection of the direction of motion changes from parallel to serial. At large displacements, performance depends on more basic features, such as appearance and disappearance. In contrast, performance for SR motion remains unchanged even when the detection of appearance and disappearance is impossible.

In our experiments, we regarded observers' response time as an indication of the processing time of the perceptual task (*3*). When an observer was searching for a particular feature among a group of objects sharing the same feature, if response time was constant regardless of the size of the group (subject to constraints such as retinal eccentricity), then we assumed that the features were processed in parallel. If response time increased with the size of the array, keeping a fixed error rate, then we assumed that a serial search took place.

Clearly visible dark squares of 7.5 × 7.5 minutes of arc, which we call dots, were used as stimuli. The perception of motion was created by two frames serially flashed on a bluish screen of a Symbolics Lisp Machine. Eight well-trained observers participated in these experiments; each experiment was performed by at least two observers. Results for three observers, one of the authors and two students who were unfamiliar with the purpose of the experiments, were plotted. The observers were asked to press a given keyboard key in response to the visual stimuli as accurately and as rapidly as possible. Exposure times were limited to 48 msec per frame to prevent a second fixation at the screen. The interstimulus interval was zero, and no masking was used. Response time was measured from the onset of the second frame. The response time increased with a decrease of the array density, so that we kept the separation between the dots fixed at approximately an average of 75 minutes of arc in all the experiments. This separation assures clear, unambiguous correspondence between the moving dots.

We tested for the detection of motion per se as well as for the direction of motion. The detection of a moving dot while dots in the

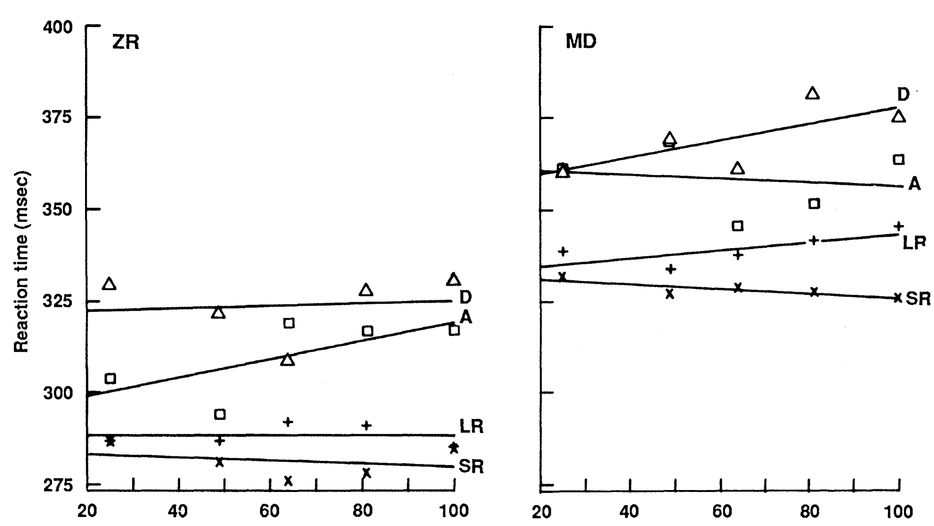

Fig. 1. Reaction times for two observers, ZR and MD, plotted as a function of the number of stationary dots in the array to be searched. Results from four classes of experiments are shown: SR, short-range motion; LR, long-range motion; A, appearance of a dot; D, disappearance of a dot. All plotted reaction times represent the mean of at least 100 trials. The typical standard error in these experiments is 7 msec. The percentage of correct responses is about 94% in each experiment. Performance seems to be parallel in all four cases.

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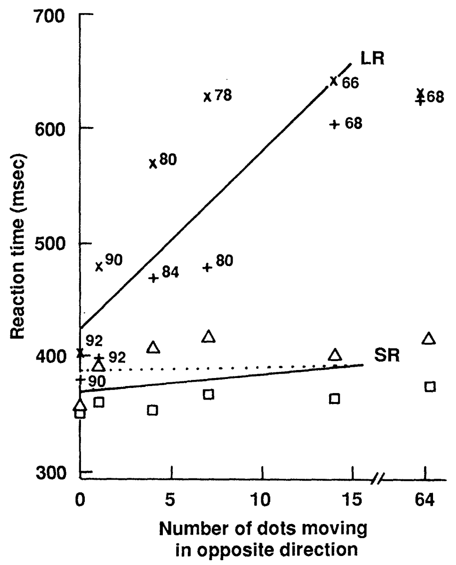

Fig. 2. Reaction times of two observers for the detection of a dot moving in one direction (to the right) as a function of the number of dots moving in the opposite direction. The array contained 64 dots; moving and stationary dots were randomly chosen. Results of observers MS and MD from two classes of experiments are shown. Symbols: (□) MS, SR motion; (△) MD, SR motion; (+) MS, LR motion; (×) MD, LR motion. The dotted line represents the average results of the same observers for SR motion experiment, but with exposure time 16 msec per frame. Typically the percentage of correct responses was 94% for SR motion. The numbers near the data points indicate the percentage of correct responses for LR motion.

background remained stationary was regarded as a motion detection task. The observer's task in this case was to decide whether something moved or nothing changed. The moving dot had to be detected regardless of its direction of motion, while in the surrounding visual field there was a variable number of stationary dots. The detection was considered parallel if detection time was independent of the number of stationary dots.

Motion detection was examined for various displacements; we present results for two displacements. SR displacements were those of the size of the dot and LR displacements were of 25 minutes of arc. The number of stationary dots varied in these experiments from 25 to 100 (since the density was fixed, the arrays subtended 5.5 to 13.7 degrees of the visual angle). Our results show that motion detection under these conditions was performed in parallel regardless of the displacement size (Fig. 1). At this stage it was still unclear whether detection was based on the motion itself or on other possible components of apparent motion.

We next examined the detection of direction of motion. The existence of detectors for direction of motion has been suggested by several investigators (*7*). A straightforward extension of the previous task would have been to ask the observers whether the dot moved to the right or to the left with respect to a variable number of stationary dots. Such an experiment would be inconclusive, however. Since we have shown that a moving dot can be detected by a parallel process, if another step of search is required to determine the direction of the moving dot, then a single shift of the serial process could suffice for making the required distinction. Reaction time patterns in this case would be independent of the number of stationary dots. Therefore, the detection of the direction of motion of a target dot was tested as a function of the number of dots moving in a different direction. Throughout these experiments the size of the array was 11 × 11 degrees (64 dots). A variable number of dots (*N*) moved in one direction, and in half the trials a test dot moved in the opposite direction with identical speed. Additional stationary dots served as background items. We assumed that a constant reaction time, independent of the number of moving elements in the background, implied that direction of motion was processed in parallel.

The results showed that the direction of motion was detected in parallel only when small motion displacements were used (less than 17.5 minutes of arc). Figure 2 shows examples of data obtained from two observers detecting the direction of motion when the test dot and the background dots moved with short and long displacements (similar to those used in Fig. 1). The average error rate in performance was about 6% for the small displacement; the rate was about the same for large displacements when a small number of dots were moved but increased with the number of dots moving in the background.

The data point corresponding to $N = 0$ indicates the case where the observer had to decide whether one dot moved to the left or to the right. The data point $N = 1$ comes from experiments where both dots moved in the same direction or in opposite directions (that is, with a single dot serving as a distractor). In this case the equal percentage of correct responses allowed a comparison to be made between small and large displacements. The increase in reaction time for the first distractor was about 30 msec. This indicates that a serial process was probably taking place (*3*). The other data points presented for the large displacement should be considered together with the performance error rate. The search time, limited by our short presentation times, caused an increase in error rate. Under constant error rate conditions, the slope for the LR motion would presumably have been steeper. The case where all the background dots moved in one direction and a single dot moved in the opposite direction is marked at a detached point at the end of the graph ($N = 64$).

For a single dot ($N = 0$), the reaction time was about the same for SR and LR motion. With additional dots, LR judgments become increasingly difficult to make. Since the dot densities used in the experiments guaranteed unambiguous correspondence between moving dots, the added difficulty with LR motion is probably not related to matching ambiguities. We also con-

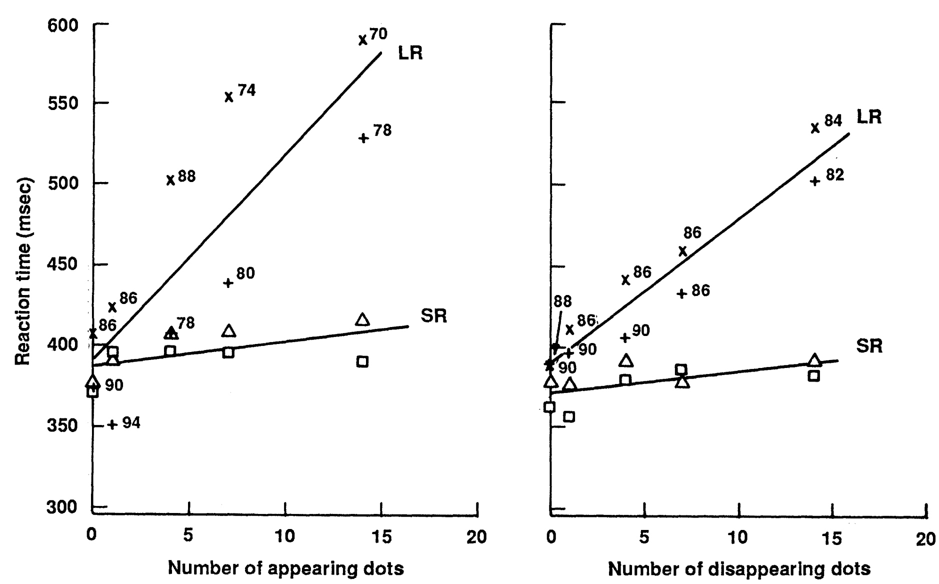

Fig. 3. Reaction times for the detection of a moving dot as a function of the number of dots appearing and disappearing in an array of 64 dots. The moving and the disappearing or appearing dots were chosen randomly; the other dots remained stationary. Two classes of motion ranges were used (as for Fig. 2). For SR motion, the percentage of correct responses was 92% (SE, 7 msec); for LR motion the percentage is marked near every data point (SE, 12 msec).

ducted similar experiments in which the exposure times of the frames were 100 and 200 msec, conditions that are known to produce optimal LR motion (*8*). The results of these experiments were not significantly different from those of experiments that used 48 msec per frame. These results suggest that the crucial parameter is the displacement of corresponding dots rather than temporal factors.

It was of interest to examine the role of the possible components of apparent motion in the motion detection process. If motion is not registered directly somehow, it could be inferred from the disappearance of the dot, its subsequent reappearance, and the spatio-temporal relations between these events. We performed several experiments to gain more insight concerning the detection of these events. We first examined the detection of an appearing and a disappearing dot, where other dots in the array remained stationary, and then the detection of motion among other appearing or disappearing dots.

In the disappearance detection test, one of the dots disappeared in the second frame in half the trials. In the appearance detection test, a new dot appeared in the second frame in half the trials. Experiments were done with the array sizes used previously (25 to 100 dots, same separation between dots). Results for the detection of a disappearing dot and that of an appearing dot are shown in Fig. 1. The detection of the appearance and of the disappearance of a single dot in a stationary array were clearly performed in parallel.

We further explored the relations between the detection of a disappearing dot and an appearing dot and the detection of motion. We tested the detection of a moving dot among appearing or disappearing background dots. The experiments were similar to those described above. The arrays subtended 11 × 11 degrees (64 dots). A test dot moved in half the trials while in the background a varying number of dots either appeared or disappeared among other stationary dots. The results show that the detection of motion among a varying number of either disappearing or appearing dots was processed in parallel only when SR motion was used. For LR motion the results were qualitatively different and indicative of a serial process (Fig. 3).

The results also show no interference of the appearing or disappearing dots with the detection of SR motion. In contrast, LR motion detection was affected by these distractors. Thus the detection of the direction of LR motion may involve the conjunction of disappearance and appearance detection. Although appearance and disappearance by themselves can be detected in parallel, their spatio-temporal conjunction may require, like various other conjunction tasks (*3*), a serial scan.

When exposure time was limited to 16 msec per frame, the detection of disappearance and appearance was no longer possible. As expected, the direction of LR motion under these conditions was also impossible to resolve (performance showed about 60% correct responses). Detection of the direction of SR motion remained unchanged. Averaged results of two subjects are plotted in Fig. 2 (dotted line). The detection of the direction of SR motion was clearly performed in parallel and independently at each location, implying the existence of an array of specialized detectors for the detection of the direction of SR, but not LR, motion.

It appears that, during the early stage of perception, the detection of the direction of motion is performed for SR motion only by a fast, parallel (preattentive) process. The detection of the direction of LR motion requires a serial search (an attentive process) and probably combines the detection of the disappearance and the reappearance of the object with additional spatio-temporal information. It is surprising to find such a serial, and relatively slow, motion detection system, since for many tasks motion must be computed relatively quickly. Such a system implies a limit on motion perception when LR motion is involved. Certain visual processes, which use the same information as LR motion (appearance and disappearance, for example), may have access to this information in a parallel fashion. For example, Ramachandran and Anstis (*9*) have reported an experiment that involved a global perception of multiple moving targets under LR conditions. It is not clear, however, whether this perception required the simultaneous parallel motion processing of the individual dots. It would be of interest to examine other perceptual tasks that rely on motion assignments, for example, whether fast global percepts could be obtained from local motion computations as in the "structure from motion" problem (*2*) when LR motion is used.

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Adipsin: A Circulating Serine Protease Homolog Secreted by Adipose Tissue and Sciatic Nerve

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Adipsin is a serine protease homolog whose primary structure was predicted from the nucleotide sequence of a differentiation-dependent adipocyte messenger RNA. Immunoblots probed with antisera to synthetic peptides identify two forms of adipsin that are synthesized and secreted by 3T3 adipocytes. These proteins of 44 and 37 kilodaltons are converted to 25.5 kilodaltons by enzymatic deglycosylation. Although adipsin is principally synthesized in adipose tissue, it is also produced by sciatic nerve and is found in the bloodstream. Because of the apparent restriction of adipsin synthesis to tissues highly active in lipid metabolism, its presence in serum, and its modulation in altered metabolic states, this molecule may play a previously unrecognized role in systemic lipid metabolism or energy balance.

DISORDERS THAT INVOLVE ADIPOSE tissue, such as obesity, are common and represent significant sources of mobidity (*1*). Intensive studies of adipocyte biochemistry over the past 20 years have revealed much about the hormonal control of carbohydrate and lipid metabolism. Despite these informative studies, our understanding of how adipocyte differentiation and metabolism are regulated is incomplete. New and potentially important gene products of the adipocyte have been identified by isolating complementary DNA (cDNA) clones corresponding to messenger RNAs (mRNAs) that are specifically induced during adipocyte differentiation (*2–4*). One