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Elements or Objects? Testing the Movement Filter Hypothesis

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P. McLeod, J. Driver, and J. Crisp (1988) proposed the existence of a movement filter in the human early visual system. This filter preattentively segregates all moving stimuli in the visual field from all stationary stimuli (McLeod et al., 1988) and all stimuli moving in one direction from those moving in another (P. McLeod, J. Driver, Z. Dienes, & J. Crisp, 1991). The primary experimental paradigm that provides evidence for the movement filter is the visual search task. McLeod et al. (1988) demonstrated that a target defined by motion and shape perceptually pops out of a conjunctive display. Four experiments are presented that demonstrate that the output of the movement filter may depend on global characteristics of the display. When a moving element perceptually groups with a static object, preattentive segregation does not occur. However, when the same element does not perceptually group with a static object, preattentive segregation occurs.

McLeod, Driver, and Crisp (1988) proposed the existence of a *movement filter* in the human visual system. They described this filter as a neuroanatomical system that perceptually segregates all moving stimuli in the visual field from all stationary stimuli (McLeod et al., 1988) and all stimuli moving in one direction from those moving in another (McLeod, Driver, Dienes, & Crisp, 1991). They hypothesized that the movement filter is located in the mid-temporal (MT) visual area (also called *visual area* [V] *5*) of the neocortex (McLeod, Heywood, Driver, & Zihl, 1989). This visual area contains cells that respond well to form-based features (such as line orientation) of moving stimuli but are relatively insensitive to the form-based features of stationary stimuli. Other visual areas, such as areas V1 and V2, contain groups of cells that are sensitive to form-based features of both moving and stationary stimuli. McLeod and his colleagues hypothesized that the motion-sensitive cells of area V5/MT can be attended to separately from the cells of areas V1 and V2 (McLeod & Driver, 1993). Selective attention to the motion-sensitive cells of area V5/MT would perceptually segregate the moving stimuli from the stationary stimuli while retaining information about form-based features.

The primary behavioral evidence for the movement filter described by McLeod and his colleagues comes from studies in which a visual search task was used (Driver & McLeod, 1992; Driver, McLeod, & Dienes, 1992; McLeod et al., 1988, 1991; Muller & Maxwell, 1994). Visual search tasks are designed to reveal the relative efficiency with which an observer can find a target in a cluster of distractors (e.g., Treisman & Gelade, 1980). Generally, when a target differs from the distractors by the conjunction of two feature dimensions (e.g., form and color), observers are fairly inefficient at detecting the presence of the target. However, McLeod et al. (1988) discovered that when a target differs from the distractors by the conjunction of motion (usually static vs. moving) and form (usually defined by line orientation), observers are very efficient at detecting the presence of the target (e.g., slopes relating number of distractors and reaction time [RT] are around 10 ms/element). McLeod et al. (1988) claimed that the target "pops out" of the conjunctive display because the complex cell sensitive to the target's attributes fires. For example, "the presence of a moving X among stationary Xs and moving Os can be signaled by activity of cells in area MT sensitive to a line at 45°" (McLeod et al., 1988, p. 155).

It is important to note that visual displays do not always segregate on the basis of motion. For example, Nakayama and Silverman (1986) presented participants with targets defined by motion (up vs. down) and color (red vs. blue). Their participants used a slow serial search strategy (slopes > 100 ms/element) to judge the target's presence in a conjunctive display. It is noteworthy that the motion component of Nakayama and Silverman's display was characterized by moving pixels that defined a rectangular object. Because moving pixels describe a static object, the theoretical distinction between moving and static objects is equivocal. At a local level of perceptual analysis, the moving pixels are relevant. At a more global level of perceptual analysis, the static rectangular object is relevant. In contrast, the experiments that demonstrate fast serial or parallel search in conjunctive displays have defined the target by unequivocal element movement (Driver & McLeod, 1992; Driver et al., 1992; McLeod et al., 1988, 1991; Muller & Maxwell, 1994). For example, the target element may be an upward moving X in the presence of upward moving Os and static Xs. Such a display retains a clear theoretical distinction between moving and static objects.

Interestingly, the dichotomy between local and more global perceptual analysis is instantiated in the structure of the visual system (Zeki, 1993). Specifically, the cells in layer

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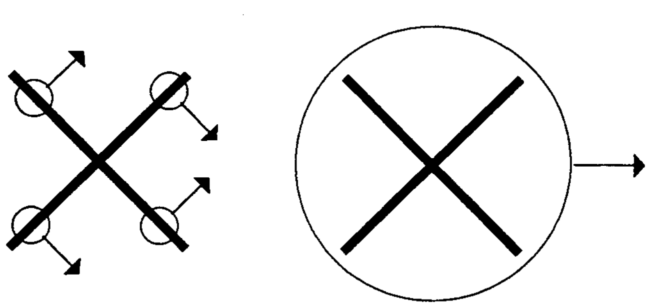
4β of area V1 are sensitive to both direction of motion and line orientation. These cells, however, are sensitive only to the direction of the local features of a stimulus (see Figure 1). In contrast, the orientation-sensitive cells in area V5/MT respond to direction on a more global level. These cells respond to the direction of the entire object, not simply to the direction of its component parts (see Figure 1).

If the movement filter is primarily located in the V5/MT area of the visual cortex and those cells are more sensitive to global than local motion, the movement filter may primarily operate on the perceptual level of the whole object. It would be easier for such a filter to segregate motion comprised of more global objects (e.g., the displays of McLeod et al., 1988, 1991) than to segregate motion comprised of local elements within a larger object (e.g., the displays of Nakayama & Silverman, 1986). However, the movement filter as proposed by McLeod and his colleagues appears to be a local component feature detector (see the quote by McLeod et al., 1988, presented earlier). That is, the presence of a target is determined by the activation of cells sensitive to a local feature (e.g., a moving 45° line) of a larger stimulus (e.g., a moving X). Such a filter would segregate motion based only on the attributes of the local features of the object. To better understand the movement filter, one must determine the perceptual level of analysis (local or global) on which the movement filter operates.

The present research was designed to determine whether the movement filter primarily operates on local features or global objects. I conducted four experiments that examined observers' abilities to detect moving targets that are either whole objects or elements within larger objects in the visual search task. If the movement filter relies on local component detection (termed the *local-movement filter hypothesis*), observers should respond equally fast to all moving stimuli, irrespective of whether the moving elements are whole objects or elements within larger objects. If, however, the movement filter relies on global object detection (termed the *global-movement filter hypothesis*), it should be easier for observers to detect moving whole objects than moving elements within larger objects.



Response of Cells in Layer 4β of V1

Response of Cells in V5/MT

Figure 1. Cells in layer 4β of visual area V1 are sensitive to the direction of the motion of the local features, whereas cells in V5/MT (MT = mid-temporal) are sensitive to the direction of the motion of the whole object.

General Method

In all experiments the traditional visual search task was used (e.g., Treisman & Gelade, 1980). The set of stimuli used for each experiment was created with a factorial combination of two feature dimensions, each having two feature values. The feature dimensions studied were motion (M) and form (F). The levels of motion were *static* (S) and *moving to the left* (L). The levels of form were *vertical* (|) and *tilted* (\). Thus, there were four possible stimuli: $M_SF_|$, $M_SF_\backslash$, $M_LF_|$, $M_LF_\backslash$.

For each observer, one of the stimuli described above was chosen as the target, and two distractors were chosen on the basis of the target's attributes. Specifically, each of the two distractors had exactly one feature in common with the target. For example, if the target was $M_SF_|$, the two distractors were $M_SF_\backslash$ and $M_LF_|$. Each observer was assigned a target and the two appropriate distractors. Target–distractor sets were counterbalanced between participants. The observer's target did not change during the experiment. The targets and distractors for each experiment are described in the respective *Stimuli* sections.

On each trial, the observer was presented a display that contained 3, 11, or 19 stimuli. Each display consisted of a vector of 25 imaginary rows, subtending approximately 16° vertically. Each distractor and target stimulus was randomly presented in 1 of the 25 rows. Only half the displays contained the target. The observer's task was to judge, as quickly as possible, whether a target was present in each display. The observer responded by pressing either the *d* or the *k* key on the computer keyboard. The key indicating a positive response was counterbalanced between participants.

Each experimental session was divided into three blocks: two blocks of *single-feature trials* (one for each distractor type) and one block of *conjunction trials* (both distractor types present). Single-feature trials are trials in which only one type of distractor is present. Therefore, the observer can determine the presence of the target on the basis of the presence or absence of the feature the target does not have in common with the distractor (e.g., if the target is a moving vertical line and the distractor is a static vertical line, the observer can detect the target by searching for motion). Conjunction trials are trials in which both types of distractors are present. Because each distractor has a different feature in common with the target, the observer cannot determine the presence of the target on the basis of the presence or absence of a single feature. The observer must make his or her judgment on the basis of the conjunction of features. The order of the blocks was randomized between participants. Each block contained 148 trials, and a target was present in the display in 74 (50%) of those trials. For the 74 trials in which a target was present in the conjunction block, there was an equal number of each distractor type. For the 74 trials in which a target was not present in the conjunction block, 37 trials contained an extra stimulus of Distractor Type A, and 37 trials contained an extra stimulus of Distractor Type B.

Between 1 and 4 individuals participated simultaneously, each in a separate walled cubicle in a dark room. Before each block, instructions were presented on the computer that verbally described and visually presented the target and distractor(s) included in the trials in that block. After the instructions, the observer was presented with 12 practice trials, followed by the experimental trials. For both experimental and practice trials, feedback was visually presented (either the word CORRECT or INCORRECT was displayed on an otherwise blank screen) for 500 ms. Incorrect trials were randomly represented later in the session. The observer was allowed a self-timed break after each block. Each experimental session lasted approximately 40 min.

Experiment 1

Experiment 1 was an exploration of whether observers would be equally sensitive to moving whole objects and moving elements within larger objects. In this experiment, observers were presented with a visual search task in which the feature dimensions studied were *line orientation* (levels: 45° vs. 90°) and *line motion* (levels: static vs. moving to the left). For one group of observers, called the *object* (OBJ) *group,* each line moved through space as an object (virtually identical to the displays used by McLeod et al., 1991). This condition retained an unequivocal distinction between moving and static objects. For the second group of observers, called the *element within an object* (EOBJ) *group,* the lines moved within rectangular windows (i.e., the lines perceptually grouped with the windows). Because the moving lines in this condition were contained within static windows, the distinction between moving and static objects was equivocal. In both conditions, the relevant information was the orientation and motion status of the lines. The local-movement filter hypothesis predicts that the complex cells sensitive to the target's attributes should be equally sensitive to the moving lines in both conditions. Therefore, observers' search rates in the OBJ group should be equivalent to those in the EOBJ group. The global-movement filter hypothesis predicts effortless segregation of moving whole objects. In the OBJ group, because the moving elements were whole objects, quick search rates should result. However, in the EOBJ group, the moving elements could perceptually be grouped with the rectangular windows. In such a case, the rectangular windows become the global objects, and because the motion status of the windows is irrelevant to the task, slow search rates should result.

Method

Participants

Forty-eight students from the general psychology subject pool volunteered to participate. All students were naive as to the task and received course credit for participation.

Apparatus

All stimuli were presented on a 13-in. (33.02 cm) video graphics array (VGA) color monitor with a 60-Hz refresh rate controlled by an 80486 microcomputer using DOS. The resolution of the monitor was 640 × 480.

Stimuli

OBJ group. Each stimulus consisted of a single line. The feature dimensions examined were line orientation and motion (see Figure 2). The feature values of line orientation were a 45° line (/) and a 90° line (|), each subtending approximately 0.61° (vertically). The feature values of motion were static and movement to the left at 2.4 deg/s. The screen was refreshed every 16.7 ms. The stimuli appeared to move smoothly.

Each trial consisted of a vector of 25 imaginary rows, subtending approximately 16° vertically. The vertical position of each stimulus was randomly selected. Each stimulus was placed randomly along the horizontal axis within 2° of the center of the screen. The display remained visible until either the observer responded or the first moving stimulus exited the computer screen (subtending approximately 24° horizontally).

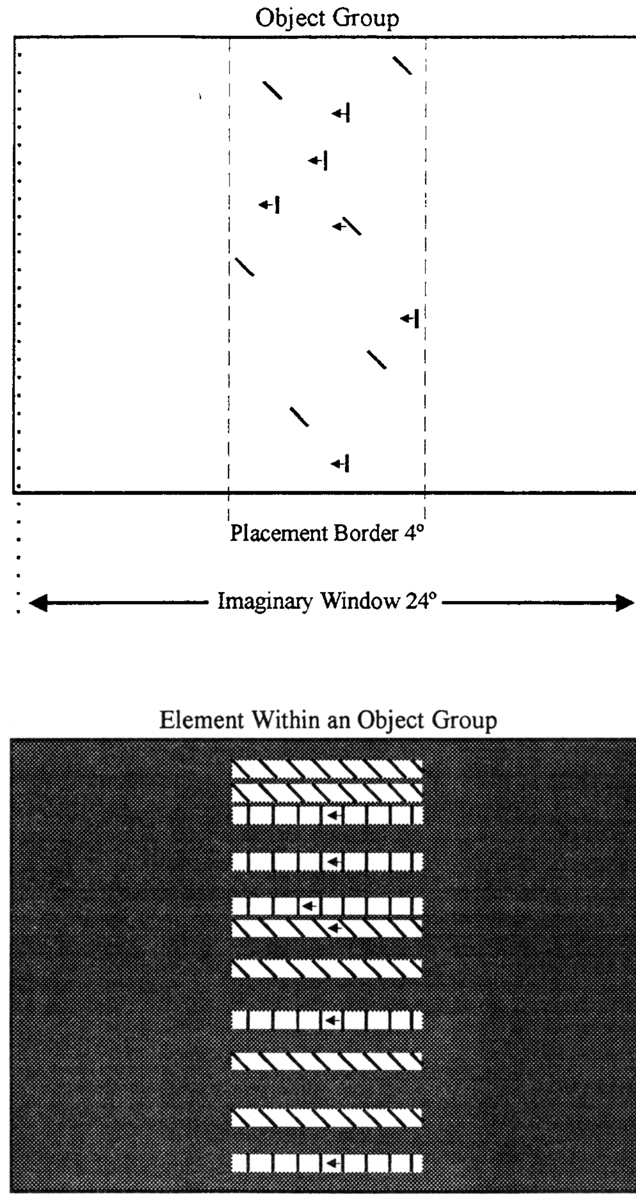


Figure 2. Example of the conjunctive displays for the object and element within an object conditions of Experiment 1. Arrows indicate moving elements. All elements were placed within 2° of the vertical center of the display before movement began. In the object condition, moving elements moved across the screen. In the element within an object condition, elements moved within a 4° window centered on the screen. The vertical position of each stimulus was randomly selected from 25 imaginary rows (fewer rows and darker gray are shown for visual clarity).

EOBJ group. Each stimulus consisted of a rectangular window (subtending 0.61° vertically and 4° horizontally) that contained eight equally spaced lines (see Figure 2). The starting positions of the lines were randomized between stimuli. The orientation of the lines within the stimulus was either a 45° line (/) or a 90° line (|). These lines were either static or moved to the left at 2.4 deg/s. When a moving line exited one edge of a stimulus, a line reappeared on the other edge. The screen was refreshed every 16.7 ms. The stimuli appeared to move smoothly.

Each trial consisted of a vector of 25 imaginary rows, subtending approximately 16° vertically. The vertical position of each stimulus was randomly selected. Each stimulus was placed randomly along the vertical axis of the center of the screen. The display remained visible until the observer responded.

Procedure

The procedure used for Experiment 1 was identical to that described in the General Method section. Twenty-four observers viewed the OBJ display, and the remaining 24 observers viewed the EOBJ display. Half the observers in each group were assigned a static target, whereas the remaining observers were assigned a moving target.

Results

To analyze the data, I conducted a robust regression, RT = f (number of stimuli), on each observer's data. The robust regression procedure was used to reduce the effects of outliers (Becker & Chambers, 1984). The observers' slopes and intercepts were then submitted to an analysis of variance (ANOVA) for each display type (i.e., single feature orientation, single feature motion, and conjunction display). This ANOVA assessed the effects of stimulus type (OBJ vs. EOBJ) and target motion (static vs. moving) on the observers' slopes and intercepts. This analysis was performed separately for target-present and target-absent trials. The slopes and intercepts for all conditions are shown in Table 1.

Conjunctive Display

The results indicate that observers detected the OBJ target much more efficiently than the EOBJ target. For the target-present conjunctive displays, there was a significant difference only between the observers' response patterns in the OBJ and EOBJ conditions, such that observers' slopes, $F(1, 44) = 44$, $p < .001$, $MSE = 246$, and intercepts, $F(1, 44) = 32.6$, $p < .001$, $MSE = 30{,}139$, in the OBJ condition were less than those in the EOBJ condition. The data from the target-absent trials echoed those of the target-present data: There was a main effect only of stimulus type for observers' slopes, $F(1, 44) = 110.2$, $p < .001$, $MSE = 679$, and intercepts, $F(1, 44) = 30.46$, $p < .001$, $MSE = 40{,}691$. There were no other significant effects. This pattern of data indicates that observers detected the OBJ target much more efficiently than the EOBJ target in the conjunctive condition.

Single-Feature Displays

It was of secondary importance to show that detection of the single features was equally salient in the OBJ and EOBJ displays. One can assess this by examining the slopes and intercepts from the single-feature displays. For the target-present, single-feature displays in which the target differed from the distractors by line orientation, there were no significant effects on the observers' slopes. Their mean slope ($M = 2$, $SD = 4.69$) did not differ from zero, $F(1, 44) = 0.36$, $MSE = 22$. Observers' intercepts for the detection of line orientation in a single-feature display were affected by stimulus type, $F(1, 44) = 15.05$, $p < .001$, $MSE = 6{,}273$, and by an interaction between motion and stimulus type, $F(1, 44) = 5.94$, $p = .01$, $MSE = 6{,}273$. The interaction revealed that observers' intercepts for a moving target in the EOBJ condition were greater than those of all other conditions. The data for the target-absent trials echoed those of the target-present displays, with the frequently cited exception that RT was related to the number of stimuli in target-absent trials (e.g., Treisman & Gelade, 1980). Specifically, there was no significant effect on slope, but observers' intercepts were affected by stimulus type, $F(1, 44) = 53.17$, $p < .001$, $MSE = 11{,}661$, and an interaction between motion and stimulus type, $F(1, 44) = 7.09$, $p = .01$, $MSE = 11{,}661$. There were no other significant effects. This pattern of data indicates that, although it took observers longer to determine the line orientation of a moving element within an object, observers in all target-present conditions detected line orientation in parallel.

For the target-present, single-feature displays in which the target differed from the distractors by motion status, observ-

Table 1
Mean Slopes (in Milliseconds/Element) and Intercepts (in Milliseconds) for Detection of a Target in the Object (OBJ) and Element Within an Object (EOBJ) Conditions of Experiment 1

	Moving OBJ				Static OBJ				Moving EOBJ				Static EOBJ			
	Intercept		Slope		Intercept		Slope		Intercept		Slope		Intercept		Slope	
Condition	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Conjunction																
Target present	709	32	12	1	770	32	10	1	1041	64	41	5	1010	62	41	7
Target absent	782	52	19	2	789	44	19	2	1141	65	98	10	1073	68	98	11
Line orientation																
Target present	626	23	2	1	651	23	1	1	770	23	3	2	685	23	2	1
Target absent	627	26	11	3	657	19	12	2	937	37	18	9	801	38	14	3
Motion																
Target present	529	18	1	1	659	37	4	1	652	25	−2	1	918	36	12	3
Target absent	598	23	0	1	719	49	7	1	766	65	0	1	1079	46	34	7

ers' slopes were affected by motion, $F(1, 44) = 34.50$, $p < .001$, $MSE = 26$, and by an interaction between motion and stimulus type, $F(1, 44) = 14.29$, $p < .001$, $MSE = 26$. The interaction revealed that observers' slopes for a static target in the EOBJ condition were greater than the detection of a target of all other conditions. Observers' intercepts for the detection of motion in a single-feature display were affected by stimulus type, $F(1, 44) = 41$, $p < .001$, $MSE = 10{,}732$; motion, $F(1, 44) = 44$, $p < .001$, $MSE = 10{,}732$; and an interaction between motion and stimulus type, $F(1, 44) = 5.23$, $p = .01$, $MSE = 10{,}732$. The interaction revealed that observers' intercepts for a moving target in the OBJ condition were less than those of the moving EOBJ condition and static OBJ condition, whereas their intercepts for a static target in the EOBJ condition were greatest. The same pattern of effects was essentially found for target-absent trials: Observers' slopes were affected by stimulus type, $F(1, 44) = 11.72$, $p = .001$, $MSE = 118$; motion, $F(1, 44) = 26.56$, $p < .001$, $MSE = 118$; and an interaction between motion and stimulus type, $F(1, 44) = 12.89$, $p < .001$, $MSE = 118$. Observers' intercepts were affected by stimulus type, $F(1, 44) = 20.25$, $p < .001$, $MSE = 28{,}043$; motion, $F(1, 44) = 29.88$, $p < .001$, $MSE = 28{,}043$; and an interaction between motion and stimulus type, $F(1, 44) = 3.97$, $p = .05$, $MSE = 28{,}043$. The pattern of target-present data indicates that the time it took observers to detect a static target among moving distractors in the EOBJ condition was greater than in the other conditions and was minimally related to the number of stimuli.

Error Data

To determine whether there were effects of accuracy, I analyzed the observers' error rates with a two-way ANOVA on errors as predicted by stimulus type and target motion. Not surprisingly, the overall mean error rate ($M = 0.06$, $SD = 0.04$) was significantly greater than zero, $F(1, 44) = 87.16$, $p < .001$, $MSE = 0.0021$. However, there was no effect of stimulus type, $F(1, 44) = 0.38$, $MSE = 0.0021$; motion, $F(1, 44) = 1.4$, $MSE = 0.0021$; or an interaction between the two, $F(1, 44) = 0.04$, $MSE = 0.0021$. This indicates that observers were equally accurate in all conditions.

Discussion

The results of the experiment were clear. The relatively shallow slopes in the OBJ conjunctive display condition indicate that observers were very efficient at detecting the target. The slopes for these observers were similar to those found by researchers who claimed segregation by the movement filter (e.g., McLeod et al., 1991). In contrast, the relatively steep slopes in the EOBJ conjunctive display condition indicate that observers used a slow serial search strategy. Together, these data suggest that observers do not detect moving whole objects and moving elements within a larger object at the same rate.

As stated earlier, the movement filter, as proposed by McLeod et al. (1988), is a local component detecting system. Because the local components of the EOBJ and OBJ target were identical, the hypothesized complex cells that are sensitive to the conjunction of motion and line orientation attributes should have responded equally well to both the OBJ and the EOBJ targets. Therefore, for the local-movement filter hypothesis to explain the steep slopes in the EOBJ conjunctive condition, one must posit that the local components were less salient in the EOBJ condition than in the OBJ condition. The data suggest that this was not the case for those displays that contained a moving target because the moving targets were detected in parallel for all single-feature displays. However, there was evidence that the single features were not equally salient for displays that contained a static EOBJ target. Specifically, observers found it somewhat more difficult to detect a static EOBJ target than a static OBJ target in the motion single-feature display.

It is important to note that the slow serial search strategy used by observers to identify the presence of the EOBJ target in the conjunctive display cannot be explained by the shallow slope associated with the detection of the static EOBJ target in the motion single-feature display for several reasons. First, the slope for the detection of the static target in the motion single-feature display was similar to single-feature slopes found by other researchers examining motion (e.g., Muller & Maxwell, 1994). Therefore, the slope found in the single-feature motion condition was not unusually large. Second, the moving EOBJ target perceptually popped out of the motion single-feature display. Therefore, if the observers' difficulty in detecting the static EOBJ target in the motion single-feature display was related to the steep slopes for the conjunctive display, one would predict an asymmetry between the observers' slopes for the detection of the static and moving EOBJ targets in the conjunctive display. The data revealed no asymmetry in slopes between the static and moving EOBJ targets in the conjunction display (41 ms/stimulus for each condition). Therefore, the slow serial search strategy used by the observers to identify the presence of the EOBJ target in the conjunctive display cannot be explained by the salience of local features.

The data from Experiment 1 are consistent with the global-movement filter hypothesis. If the movement filter resides in area V5/MT, as suggested by McLeod et al. (1988, 1989), then the filter may operate on objects rather than on local features. In the OBJ display, the relevant stimuli (i.e., the moving lines) were autonomous units and were therefore subject to segregation by the global-movement filter. However, in the EOBJ display, the relevant stimuli could have been perceived as being part of a larger unit. Specifically, the multiple elements in each EOBJ stimulus may have grouped both with each other and with the static window. In such an instance, the cells in V5/MT would respond to the motion status of the rectangular window. Because the motion status of the rectangular window was irrelevant to the task, the global-movement filter was ineffective.

Although the results from Experiment 1 suggest that the movement filter operates on objects rather than on local features, there were several differences between the OBJ and EOBJ conditions. Specifically, (a) a visible window was present in the EOBJ condition but was absent in the OBJ condition; (b) there were more lines present in the EOBJ condition than in the OBJ condition; (c) the lines of the EOBJ condition wrapped, whereas those of the OBJ condition did not; and (d) the display time for both conditions may not have been equal because the display was removed in the OBJ condition when a line exited the screen. In Experiment 2, I removed the latter three differences. In Experiment 3, I removed the first difference.

Experiment 2

Experiment 2 was an attempt to equate the display differences between the OBJ and EOBJ conditions. In this experiment, stimuli were created that were identical except for the visibility of a rectangular window. The moving elements in the OBJ condition consisted of a single line moving within an invisible rectangular window. The visual angle of this window subtended 4°, and when the line exited one end of the window it reappeared on the other end. The EOBJ condition was identical to the OBJ condition, except that the window was made visible by slightly graying the background of the display. If these differences in the OBJ and EOBJ displays correctly explained the results of Experiment 1, observers should identify the target equally well in both conditions. If, however, a difference in difficulty of identifying the target in the conjunctive display between the two conditions remains, one can conclude that the visibility of the rectangular window produced the results. Such a finding may support the global-movement filter hypothesis.

Method

Participants

Twenty-eight students from the general psychology subject pool volunteered to participate. All students were naive as to the task and received course credit for participation.

Apparatus

All stimuli were presented on a 13-in. (33.02 cm) VGA color monitor with a 60-Hz refresh rate controlled by an 80486 microcomputer using DOS. The resolution of the monitor was 640 × 480.

Stimuli

The feature dimensions examined were line orientation and motion. The feature values of line orientation were a 45° line (/) and a 90° line (|), each subtending approximately 0.61° (vertically). The feature values of motion were static and movement to the left at 2.4 deg/s. The screen was refreshed every 16.7 ms. The stimuli appeared to move smoothly.

A stimulus consisted of a single line within a rectangular window subtending 0.61° vertically and 4° horizontally. The line in each stimulus was placed randomly along the horizontal axis within the rectangular window.

Each trial consisted of a vector of 25 imaginary rows, subtending approximately 16° vertically. The vertical position of each stimulus was randomly selected. Each stimulus was placed randomly along the vertical axis of the center of the screen. The display remained visible until the observer responded.

For the OBJ group, the rectangular window was not visible. That is, the color of the rectangular window and the color of the background were the same (white). Thus, the line looked like an autonomous unit (see Figure 3). For the EOBJ group, the color of the rectangular window (white) was different from the color of the background (light gray). Thus, the line looked as if it was contained within the window (see Figure 3). In all other respects, the stimuli for the OBJ and EOBJ groups were identical.

Procedure

The procedure used for Experiment 2 was identical to that of Experiment 1. Fourteen observers viewed the OBJ display, and the

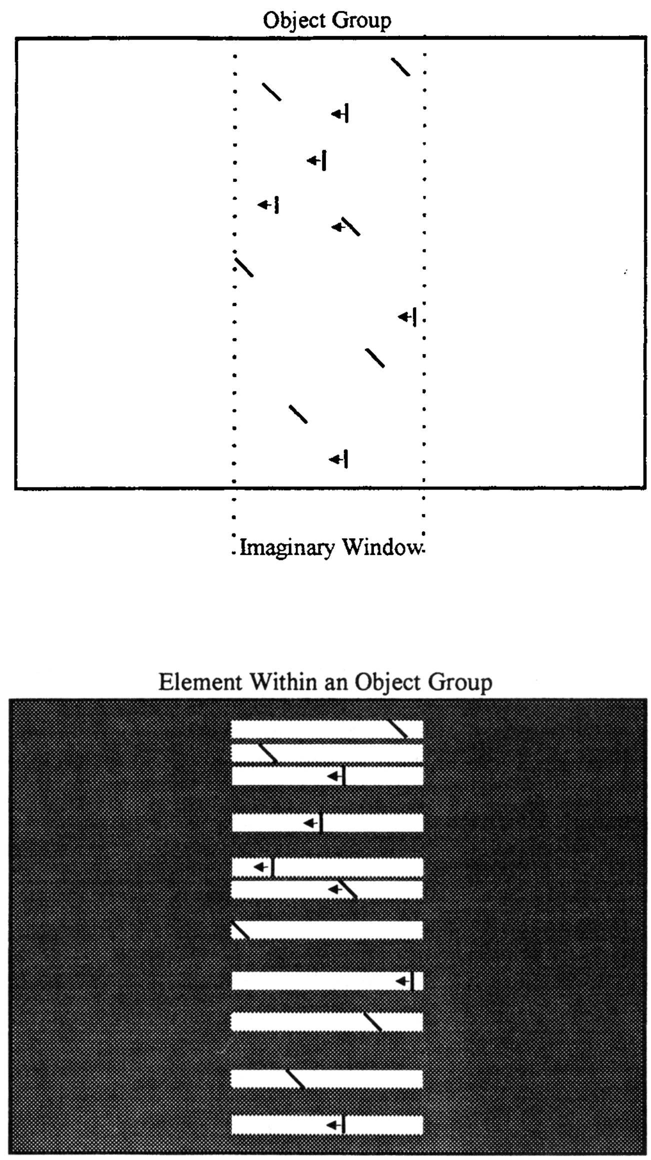


Figure 3. Example of the conjunctive display for the object and element within an object conditions of Experiment 2. Arrows indicate moving elements. All elements were placed within 2° of the vertical center of the display before movement began. Elements moved within a 4° invisible window centered on the screen. The vertical position of each stimulus was randomly selected from 25 imaginary rows (fewer rows and darker gray are shown for visual clarity).

remaining 14 observers viewed the EOBJ display. Half the observers in each group were assigned a static target, whereas the remaining observers were assigned a moving target. Because the visible static window creates static vertical lines, the target line orientation was 45° for all observers.

Results

The same procedure used in Experiment 1 was used to analyze the data in Experiment 2. That is, a robust regression was computed on each observer's data, and all the observers' slopes and intercepts were submitted to an ANOVA for each display type. This analysis was performed separately for target-present and target-absent trials. The slopes and intercepts for all conditions are shown in Table 2.

Conjunctive Display

The results indicate that observers detected the OBJ target much more efficiently than the EOBJ target. For the target-present conjunctive displays, there was a significant difference between the observers' response patterns in the OBJ and EOBJ conditions, such that the slopes, $F(1, 24) = 12.99$, $p = .001$, $MSE = 131$, in the OBJ condition were less than those in the EOBJ condition. There were no other significant effects on observers' slopes or intercepts. The same pattern of data was found for the target-absent trials: There was a main effect only of stimulus type on observers' slopes, $F(1, 24) = 4.53$, $p = .04$, $MSE = 890$. Again, this pattern of data indicates that observers detected the OBJ target much more efficiently than the EOBJ target.

Single-Feature Displays

For the target-present, single-feature displays in which the target differed from the distractors by line orientation, observers' slopes were affected by stimulus type, $F(1, 24) = 4.70$, $p = .04$, $MSE = 4$. However, in both conditions the slope was close to zero. There were no other significant effects on observers' slopes or intercepts for target-present trials. Results from the target-absent displays were relatively similar to those of the target-present displays: There was a significant effect of stimulus type on slope, $F(1, 24) = 8.53$, $p = .008$, $MSE = 36$. However, there was also a significant effect of motion on observers' slopes, $F(1, 24) = 4.72$, $p = .04$, $MSE = 36$, and intercepts, $F(1, 24) = 10.04$, $p = .004$, $MSE = 6{,}418$, such that observers' were more efficient at detecting the absence of a moving target than a static target. There were no other significant effects on observers' slopes or intercepts for target-absent trials. The pattern of data for target-present trials indicates that observers in all conditions detected line orientation in parallel.

For the target-present, single-feature displays in which the target differed from the distractors by motion, observers' response patterns were affected only by motion, such that the observers' slopes, $F(1, 24) = 16.28$, $p < .001$, $MSE = 18$, and intercepts, $F(1, 24) = 7.34$, $p = .01$, $MSE = 9{,}316$, for the static targets were greater than those for the moving targets. Again, the pattern of data for the target-absent trials was similar to that of the target-present trails: There was a significant main effect only of motion on intercepts, $F(1, 24) = 14.91$, $p < .001$, $MSE = 43{,}245$. This pattern of data indicates that static targets were more difficult to detect than moving targets in both the OBJ and EOBJ conditions.

Error Data

To determine whether there were effects of accuracy, I analyzed the observers' error rates by computing a two-way ANOVA on errors as predicted by stimulus type and target motion. Not surprisingly, the overall mean error rate ($M = 0.039$, $SD = 0.037$) was significantly greater than zero, $F(1, 24) = 37.71$, $p < .001$, $MSE = 0.0014$. However, there was no effect of stimulus type, $F(1, 24) = 0.55$, $MSE = 0.0014$; motion, $F(1, 24) = 1.38$, $MSE = 0.0014$; or an interaction between the two, $F(1, 24) = 1.18$, $MSE = 0.0014$. This indicates that observers were equally accurate in all conditions.

Discussion

The data from Experiment 2 reveal that observers quickly detected the presence of the target in the conjunctive display

Table 2
Mean Slopes (in Milliseconds/Element) and Intercepts (in Milliseconds) for Detection of a Target in the Object (OBJ) and Element Within an Object (EOBJ) Conditions of Experiment 2

	Moving OBJ				Static OBJ				Moving EOBJ				Static EOBJ			
	Intercept		Slope		Intercept		Slope		Intercept		Slope		Intercept		Slope	
Condition	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Conjunction																
Target present	789	47	10	2	769	54	10	2	769	29	26	4	664	38	25	7
Target absent	894	43	40	7	882	74	34	6	919	60	70	18	886	61	53	9
Line orientation																
Target present	582	33	−1	1	536	25	−1	1	586	23	0	1	580	26	0	1
Target absent	691	34	−1	1	548	38	3	1	696	26	5	3	648	20	10	3
Motion																
Target present	571	25	−1	1	667	47	4	1	622	31	0	1	722	39	8	3
Target absent	667	33	1	2	962	123	8	4	731	40	13	9	1,044	82	17	7

when the rectangular window was invisible. However, when the rectangular window was visible, observers used a slow serial search to detect the presence of the target in the conjunctive display. This result suggests that the data from Experiment 1 could not be explained by the (a) the extra lines present in the EOBJ condition, (b) the wrapping of the lines in the EOBJ condition, or (c) the difference in display time between the conditions. Therefore, only the visibility of the rectangular window could have influenced observers' search rates in the EOBJ condition.

The difference in observers' ability to identify the presence of the OBJ and EOBJ target in the conjunctive display of Experiment 2 could not be explained by a difference in the salience of the individual feature dimensions. Observers' mean slopes for identifying the targets in the single-feature displays were near zero in all conditions except for the identification of the static targets in the single-feature motion displays. Observers experienced some difficulty in detecting the static targets in the single-feature motion displays in both the OBJ and EOBJ conditions. Similar to the effect found in Experiment 1, this effect could not explain the differential results between the OBJ and EOBJ targets in the conjunctive display for the following reasons: (a) The small slope for the detection for the static targets in the single-feature motion displays was evident in both the OBJ and EOBJ conditions and therefore should have affected both conditions equally in the conjunctive display; (b) there was no asymmetry found between identifying moving and static targets in the conjunctive display for either condition (OBJ condition, moving = 11 ms/stimulus vs. static = 10 ms/stimulus; EOBJ condition, moving = 26 ms/stimulus vs. static = 26 ms/stimulus). Thus, because the single-feature components were equally salient in the OBJ and EOBJ conditions, the salience of single features could not explain the observers' differential performance between conditions in the conjunctive display.

In Experiment 2, the only difference between conditions was the visibility of the rectangular window in the EOBJ condition. Although this window did not interfere with the observers' ability to detect a EOBJ target in the single-feature displays, it did interfere with the observers' ability to detect an EOBJ target in the conjunctive display. It is possible, but unlikely, that the local features of the rectangular window interfered with the detection of the EOBJ target. Wolfe, Friedman-Hill, Stewart, and O'Connell (1992) have demonstrated that the mere presence of horizontal and vertical lines may interfere with the detection of a tilted line.

The data do not support the conjecture that the local features of the rectangular window interfered with the detection of the EOBJ target. A likely source of interference would be the static vertical lines created by the rectangular window. If these vertical lines interfered with the detection of the EOBJ target, their interference would have been apparent when observers were asked to identify the static EOBJ target (a 45° line) in the motion single-feature display. In this condition, the distractor was a moving 45° line. The addition of the static 90° lines of the rectangular window would create a conjunctive display. Therefore, if these vertical lines were a factor in the detection of the EOBJ target, the observers' slopes for this condition should be (a) similar to the slopes for the static EOBJ target conjunctive condition and (b) different from the slopes for the static OBJ target in the motion single-feature condition. The data refute both of these predictions.

Although the data do not support the suggestion that the local features of the rectangular window interfered with target detection in the conjunctive display, it is necessary to test this hypothesis experimentally. To conclusively demonstrate that the local features of the rectangular window did not interfere with the detection of the conjunctive target, one must show an efficient search for a target in a conjunctive display that contains the same local features produced by the rectangular window. According to the global-movement filter hypothesis, for this to occur the relevant lines must not group with the features of the rectangular window. In Experiment 3, I assessed this hypothesis.

Experiment 3

Experiment 3 was an attempt to determine whether the local features of the rectangular window interfered with the detection of the target in the conjunctive display. Experiment 3 also further assessed the validity of the global-movement filter hypothesis to explain the steep slopes of the EOBJ displays. In this experiment, stimuli were created that were identical except for the visibility of a background grid. The *no-background condition* was identical to the OBJ condition of Experiment 2. The *background condition* was identical to the no-background condition except that a grid of horizontal and vertical light gray lines was visible on the background of the display (see Figure 4). This grid was constructed so that the perimeter of the rectangular window of the stimuli was

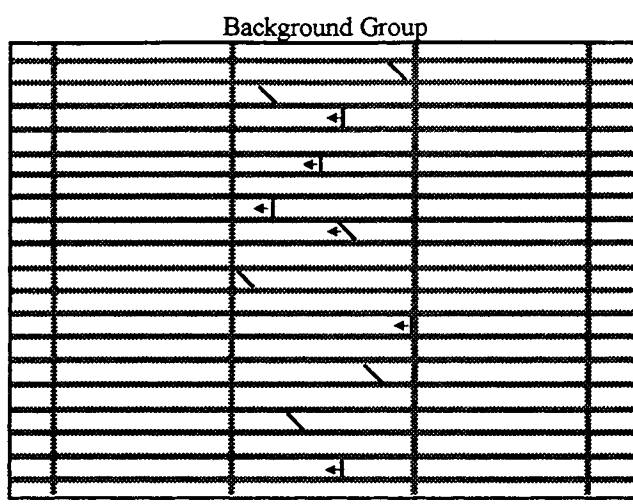


Figure 4. Example of the conjunctive display for the no-background condition of Experiment 3. Arrows indicate moving elements. All elements were placed within 2° of the vertical center of the display before movement began. Elements moved within a 4° invisible window centered on the screen. The vertical position of each stimulus was randomly selected from 25 imaginary rows (fewer rows and darker gray are shown for visual clarity).

coincident with the horizontal and vertical light gray lines on the vertical center of the display. Thus, this condition contained the horizontal and vertical light gray lines present in the EOBJ condition of Experiment 2. However, because these lines were part of a larger background grid, they did not perceptually group with the target and distractor stimuli. If the horizontal and vertical light gray lines interfered with the detection of the target in the conjunctive display of Experiment 2, observers should have difficulty identifying the target in the background condition. If, however, the targets in both conditions are detected equally easily, one can conclude that these lines did not interfere with the detection of the targets. Such a finding would suggest that the critical difference between the OBJ and the EOBJ conditions in Experiments 1 and 2 was the perceptual grouping of the rectangular window with the elements. This finding would lend support for the global-movement filter hypothesis.

Method

Participants

Fifty-two students from the general psychology subject pool volunteered to participate. All students were naive as to the task and received course credit for participation.

Apparatus

All stimuli were presented on a 13-in. (33.02 cm) VGA color monitor with a 60-Hz refresh rate controlled by an 80486 microcomputer using DOS. The resolution of the monitor was 640 × 480.

Stimuli

The feature dimensions examined were line orientation and motion. The feature values of line orientation were a 45° line (/) and a 90° line (|), each subtending approximately 0.61° (vertically). The feature values of motion were static and movement to the left at 2.4 deg/s. The screen was refreshed every 16.7 ms. The stimuli appeared to move smoothly.

A stimulus consisted of a single line within a rectangular window subtending 0.61° vertically and 4° horizontally. The line in each element was placed randomly along the horizontal axis within the rectangular window.

Each trial consisted of a vector of 25 imaginary rows, subtending approximately 16° vertically. The vertical position of each stimulus was randomly selected. Each stimulus was placed randomly along the vertical axis of the center of the screen. The display remained visible until the observer responded.

For the no-background group, the rectangular window was not visible. This display was identical to that of the OBJ group from Experiment 1. For the background group, a light gray grid consisting of horizontal and vertical lines was present. The set of rectangles formed by the lines along the vertical axis of the center of the display coincided with the perimeter of the rectangular window of the stimulus (see Figure 4). Thus, although the element was contained within a light gray rectangle, it appeared as though the rectangle grouped with the background grid, not with the element. In all other respects, the stimuli in the background and no-background groups were identical.

Procedure

The procedure used for Experiment 3 was identical to that of Experiments 1 and 2. Twenty-six observers viewed the no-background display, and the remaining 26 observers viewed the background display. Half the observers in each group were assigned a static target, whereas the remaining observers were assigned a moving target. Because the visible static window creates static vertical lines, the target line orientation was 45° for all observers.

Results

The same procedure used in Experiments 1 and 2 was used to analyze the data in Experiment 3. This analysis was performed separately for target-present and target-absent trials. The slopes and intercepts for all conditions are shown in Table 3.

Conjunctive Displays

There was no effect of background on the efficiency with which observers detected the presence of a target in the conjunctive displays. When the target was present, there

Table 3
Mean Slopes (in Milliseconds/Element) and Intercepts (in Milliseconds) for Detection of a Target in the No-Background (NB) and Background (BG) Conditions of Experiment 3

	NB moving				NB static				BG moving				BG static			
	Intercept		Slope		Intercept		Slope		Intercept		Slope		Intercept		Slope	
Condition	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Conjunction																
Target present	811	33	13	2	768	51	11	3	758	30	12	2	679	31	15	2
Target absent	995	54	32	3	820	58	34	6	857	53	41	6	757	46	40	4
Line orientation																
Target present	578	22	0	1	627	30	5	1	546	18	1	1	602	18	7	1
Target absent	645	27	2	1	819	47	5	3	645	31	2	1	839	46	13	4
Motion																
Target present	627	64	−1	1	548	20	0	1	585	19	0	1	534	26	0	1
Target absent	733	82	0	1	558	20	4	1	661	30	3	1	549	26	6	1

were no significant effects on the observers' slopes or intercepts. When the target was absent, there was a significant effect only of motion on observers' intercepts, $F(1, 48) = 6.68$, $p = .01$, $MSE = 36{,}371$, such that the observers' intercepts for detecting the absence of moving targets were greater than those for static targets. This pattern of data indicates that observers were equally efficient at detecting the targets in the background-present and background-absent conjunctive conditions.

Single-Feature Displays

For the target-present, single-feature displays in which the target differed from the distractors by line orientation, observers' patterns of response were affected by motion (static or moving), such that their slopes, $F(1, 48) = 28.56$, $p < .001$, $MSE = 12$, and intercepts, $F(1, 48) = 5.57$, $p = .02$, $MSE = 6{,}510$, were greater for the static displays than for the moving displays. Furthermore, there was a significant main effect of background (present or absent), $F(1, 48) = 4.04$, $p = .05$, $MSE = 12$, such that elements in the background display were more difficult to detect than elements in the display without the background. It is noteworthy that all slopes in both conditions were close to zero. There were no other significant effects on observers' slopes or intercepts for target-present trials. Observers' data for the target-absent trials were similar to those of the target-present data: There was a significant effect only of motion on observers' slopes, $F(1, 48) = 6.48$, $p = .014$, $MSE = 92$, and intercepts, $F(1, 48) = 22.66$, $p < .001$, $MSE = 19{,}511$. The pattern of data for the target-present trails indicates that observers in all conditions detected line orientation in parallel.

For the target-present, single-feature displays in which the target differed from the distractors by motion, there were no significant effects on observers' slopes or intercepts. For the target-absent trials, observers' patterns of responses were significantly affected only by motion, such that observers' slopes, $F(1, 48) = 6.12$, $p = .017$, $MSE = 23$, and intercepts, $F(1, 48) = 9.49$, $p = .003$, $MSE = 28{,}226$, were greater when detecting the absence of a static target than a moving target. This pattern of data indicates that observers in all conditions detected the presence of a target defined by motion in parallel. However, the absence of a static target was harder to detect than the absence of a moving target.

Error Data

To determine whether there were effects of accuracy, I analyzed the observers' error rates by computing a two-way ANOVA on errors as predicted by background and target motion. Not surprisingly, the overall mean error rate ($M = 0.04$, $SD = 0.026$) was significantly greater than zero, $F(1, 48) = 119$, $p < .001$, $MSE = 0.0007$. However, there was no effect of background, $F(1, 48) = 0.43$, $MSE = 0.0007$; motion, $F(1, 48) = 0.34$, $MSE = 0.0007$; or an interaction between the two, $F(1, 48) = 1.37$, $MSE = 0.0007$. This indicates that observers were equally accurate in all conditions.

Discussion

The data indicate that the horizontal and vertical lines in the background condition did not interfere with the detection of the target in the conjunctive display. The slopes and intercepts for the background and no-background conditions were not significantly different when the observers attempted to detect a target in the conjunctive display. This finding refutes the hypothesis that the local features of the rectangular window were the source of interference found between the EOBJ and OBJ conditions in Experiments 1 and 2.

The results of Experiment 3 provide support for the global-movement filter hypothesis. The display of the background condition of Experiment 3 and the EOBJ condition of Experiment 2 were nearly identical except for the visibility of a grid in the periphery of the displays. Both conditions contained extraneous vertical and horizontal lines, and in both conditions the relevant lines moved within a demarcated region. However, observers identified the presence of the target in the conjunctive display of the background condition of Experiment 3 with much greater ease than they did for the conjunctive display of the EOBJ condition of Experiment 2. Therefore, the global properties of the display must have influenced the observers' ability to detect the target in the two conditions. The observers' difficulty in detecting the conjunctive target in the EOBJ condition of Experiment 2 may have been the result of the perceptual grouping of the lines with the rectangular window. The background of Experiment 3 was designed so as not to group with the lines. Phenomenologically, this grouping did not occur.

Alternatively, the observers' difficulty in detecting the conjunctive target in the EOBJ condition of Experiment 2 may have been the result of the visibility of the background in the unused rows between the stimuli. For example, the background is visible in the gap between Windows 3 and 4 in Figure 3. In contrast, the background condition had empty windows in these unused rows. This subtle difference between the EOBJ and background conditions may have influenced the salience of the target. In Experiment 4, I tested this hypothesis.

Experiment 4

Experiment 4 was an attempt to determine whether the lack of intervening windows in the EOBJ condition of Experiment 2 influenced the observers' ability to detect the target. In this experiment, the stimuli were identical to those used in Experiment 2 except that in the EOBJ condition, I included empty rectangular windows in the rows that did not contain a target or distractor. If the empty grid lines between the elements in the background condition of Experiment 3 eased detection of the target, the observers' slopes in the EOBJ condition should be equal to those in the OBJ condition. If, however, the EOBJ targets remain difficult to detect, one can conclude that something other than the lack of intervening windows between elements is the cause. Such a finding would further support the supposition that the critical difference between the OBJ and the EOBJ conditions in Experiments 1 and 2 was the perceptual grouping of the rectangular window with the elements. This finding would lend support for the global-movement filter hypothesis.

Method

Participants

Fifty-two students from the general psychology subject pool volunteered to participate. All students were naive as to the task and received course credit for participation.

Apparatus

All stimuli were presented on a 13-in. (33.02 cm) VGA color monitor with a 60-Hz refresh rate controlled by an 80486 microcomputer using DOS. The resolution of the monitor was 640 × 480.

Stimuli

The stimuli were identical to those of Experiment 2 except that rectangular windows were present in all 25 rows of the EOBJ condition on every trial. However, only a subset of those windows contained targets or distractors (see Figure 5). The remaining windows were empty. The stimuli in the object condition were identical to those used in Experiment 2.

Procedure

The procedure used for Experiment 4 was identical to that used in Experiments 1–3. Twenty-six observers viewed the OBJ display, and the remaining 26 observers viewed the EOBJ display. Half the observers in each group were assigned a static target, whereas the remaining observers were assigned a moving target. Because the visible static window creates static vertical lines, the target line orientation was 45° for all observers.

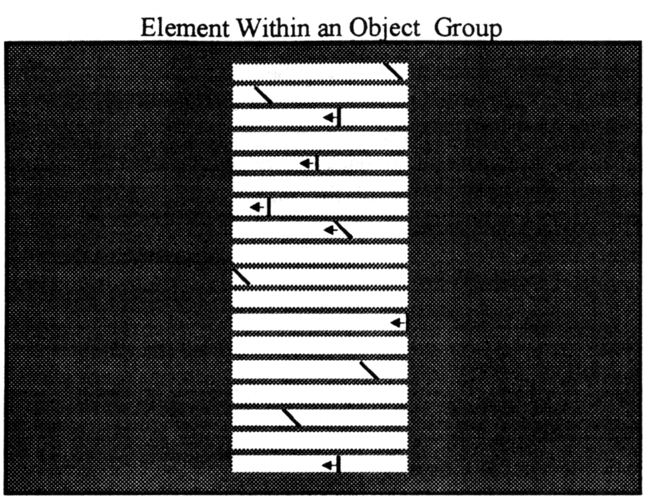


Figure 5. Example of the conjunctive display for the element within an object condition of Experiment 4. Arrows indicate moving elements. All elements were placed within 2° of the vertical center of the display before movement began. Elements moved within a 4° invisible window centered on the screen. The vertical position of each stimulus was randomly selected from 25 imaginary rows (fewer rows and darker gray are shown for visual clarity).

Results

The same procedure was used to analyze the data in Experiment 4 as was used in Experiments 1–3. This analysis was performed separately for target-present and target-absent trials. The slopes and intercepts for all conditions are shown in Table 4.

Conjunctive Display

The results indicate that observers detected the OBJ target much more efficiently than the EOBJ target. For the target-present conjunctive displays, there was a significant difference between the observers' response patterns in the OBJ and EOBJ conditions, such that observers' slopes, $F(1, 26) = 52.387$, $p < .001$, $MSE = 35$, in the OBJ condition were less than those in the EOBJ condition. There were no other significant effects on observers' slopes or intercepts. The same pattern of data was found for the target-absent trials: There was a main effect only of stimulus type on observers' slopes, $F(1, 26) = 6.357$, $p = .015$, $MSE = 504$. Again, this pattern of data indicates that observers detected the OBJ target much more efficiently than the EOBJ target.

Single-Feature Displays

For the target-present, single-feature displays in which the target differed from the distractors by line orientation, observers' slopes were affected by stimulus type, $F(1, 26) = 19.18$, $p < .001$, $MSE = 3.3$. However, in both conditions the slope was close to zero. There were no other significant effects on observers' slopes or intercepts for target-present and target-absent trials. The pattern of data for target-present trials indicates that observers in all conditions detected line orientation in parallel.

For the target-present, single-feature displays in which the target differed from the distractors by motion, observers' response patterns were affected by motion, such that the observers' slopes, $F(1, 26) = 16.4$, $p < .001$, $MSE = 20$, and intercepts, $F(1, 26) = 14.1$, $p < .001$, $MSE = 26{,}065$, for the static targets were greater than those for the moving targets. Furthermore, observers' slopes were significantly affected by stimulus type, $F(1, 26) = 19.19$, $p < .001$, $MSE = 20$, and by an interaction between stimulus type and motion, $F(1, 26) = 5.73$, $p = .025$, $MSE = 20$. The interaction revealed that observers' slopes in the static EOBJ condition were significantly greater than those of all other conditions. Again, the pattern of data for the target-absent trials was similar to that of the target-present trials: There was a significant main effect only of motion on slopes, $F(1, 26) = 15.61$, $p < .001$, $MSE = 256$, and intercepts, $F(1, 26) = 20.82$, $p < .001$, $MSE = 65{,}985$. This pattern of data indicates that static targets were more difficult to detect than moving targets, especially in the EOBJ conditions.

Table 4
Mean Slopes (in Milliseconds/Element) and Intercepts (in Milliseconds) for Detection of a Target in the Object (OBJ) and Element Within an Object (EOBJ) Conditions of Experiment 4

	Moving OBJ				Static OBJ				Moving EOBJ				Static EOBJ			
	Intercept		Slope		Intercept		Slope		Intercept		Slope		Intercept		Slope	
Condition	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Conjunction																
Target present	810	43	11	1	852	53	11	2	803	32	21	2	753	38	26	1
Target absent	925	63	25	7	960	71	42	6	984	82	50	6	907	60	49	6
Line orientation																
Target present	558	16	−1	1	575	30	−1	1	592	17	1	1	565	26	1	1
Target absent	643	37	1	1	596	40	5	2	700	42	4	2	607	25	5	1
Motion																
Target present	588	16	0	1	823	81	2	1	594	20	3	2	696	28	10	2
Target absent	669	24	2	1	1,095	124	16	4	706	37	7	2	930	54	20	5

Error Data

To determine whether there were effects of accuracy, I analyzed the observers' error rates by computing a two-way ANOVA on errors as predicted by stimulus type and target motion. Not surprisingly, the overall mean error rate ($M = 0.037$, $SD = 0.024$) was significantly greater than zero, $F(1, 26) = 129.68$, $p < .001$, $MSE = 0.0006$. However, there was no effect of stimulus type, $F(1, 26) = 2.4$, $MSE = 0.0006$; motion, $F(1, 26) = 0.53$, $MSE = 0.0006$; or an interaction between the two, $F(1, 26) = 0.01$, $MSE = 0.0006$. This indicates that observers were equally accurate in all conditions.

Discussion

The data indicate that the conjunctive target in the EOBJ condition remained much more difficult to detect than the conjunctive target of the OBJ condition, even though all rows of the EOBJ condition contained rectangular windows.[1] This finding refutes the hypothesis that intervening widows ease the detection of the target. As a consequence, the ease of detecting the target in the background condition of Experiment 3 could not have been the result of the intervening grid lines between elements.

General Discussion

The results of the present experiments indicate that object-based selection can interfere with motion cues. Observers quickly detected targets defined by a conjunction of motion and line orientation only when the motion component was whole-object motion. However, when the motion component perceptually grouped with a larger static object, observers had difficulty detecting the target. Because the local components of the OBJ and EOBJ displays in Experiment 2 were physically identical, and identical in salience, the static windows were the likely source of the observers' difficulty in detecting the EOBJ targets. Because the local features of the static windows were not a factor, as shown by Experiments 3 and 4, it is likely that the static window influenced the global perception of the display.

Although the present experiments cannot unequivocally determine how the static window influenced perception, a theoretically likely source is the perceptual grouping of moving with static elements. Specifically, the static windows may have perceptually grouped with the moving elements in the EOBJ condition. There are at least two alternative hypotheses that can explain why this perceptual grouping interfered with the observers' ability to detect the EOBJ target: (a) The movement filter operates on local features of the stimulus, but perceptual grouping of moving with static elements interfered with the normal functioning of the filter, or (b) the movement filter operates on global rather than local features of the stimulus (i.e., the global-movement filter hypothesis). Both hypotheses assume that the movement filter operates on visual information after perceptual grouping has occurred.

McLeod and Driver (1993) described the movement filter as a neuroanatomical system that perceptually segregates stimuli on the basis of their motion status. The level of perceptual analysis on which this segregation occurs is important to consider. When moving elements are part of a static object, the theoretical distinction between moving and static objects is equivocal. If the movement filter operates on a local level, the moving elements are the features on which the segregation occurs. In the present research, this hypothesis would predict that the targets in the EOBJ condition should be detected as easily as those in the OBJ condition. This did not occur. Thus, to retain the hypothesis that the movement filter detects local features, one must hypothesize that global features of the display interfered with the normal functioning of the movement filter.

The perceptual grouping of moving with static elements may have interfered with observers' ability to attend to the output of the visual areas that process motion-based features (V5/MT) separately from those that process static features

[1] The slow serial search strategy used by observers to identify the presence of the EOBJ target in the conjunctive display cannot be explained by the shallow slope associated with the detection of the static EOBJ target in the motion single-feature display for the same reasons described in Experiment 1.

(V1 and V2). Perceptual grouping of elements has been shown to interfere with observers' ability to selectively attend to individual elements of a group (Pomerantz, 1981). Indeed, an observer's inability to selectively attend to individual elements of a group has been used as a measure of the strength of perceptual grouping. It is reasonable to suspect that the perceptual grouping of moving with static elements may inhibit selective attention to elements on the basis of motion. Without the ability to selectively attend to elements on the basis of motion, targets defined by a conjunction of motion and line orientation may not pop out.

An alternative hypothesis is that the movement filter operates on global features of the stimuli rather than on local features of the stimuli. If the movement filter operates on a global level, perceptual groups are the features on which segregation occurs. In the EOBJ conditions of the present research, the moving lines may have been perceived as a part of the rectangular window. Thus, perceptual segregation would occur at the level of the rectangular window (i.e., the moving lines would have been immaterial). In the present research, all the rectangular windows were static. Therefore, the movement filter was irrelevant and perceptual segregation would not be predicted for this display. In the OBJ condition, the moving elements were autonomous. Therefore, the perceptual analysis would have been on the level of the moving elements and perceptual segregation would be predicted for that display.

As stated in the introduction, there is a neurological foundation for this finding. The cells in area V5/MT that respond to motion do so primarily on the level of the object, not the local features (Zeki, 1993). McLeod et al. (1988, 1989) claimed that the area V5/MT is critical to the motion filter. If this were true, one would predict that object-based features would override local features. The present research showed that this occurred.

The hypothesis that the movement filter operates on global features of the stimuli is intriguing because it suggests that the motion status of the whole object may have primary importance over the motion status of the local features of that object, even in early vision. From an evolutionary standpoint, perceptual segregation of all moving local features from all static local features may be of little value because of the innumerable local features present in the visual field. In contrast, perceptual segregation of moving objects from static objects may have some survival value. Moving objects are less common (by definition) and may be more meaningful than moving local features. Moving objects become even more meaningful if static objects with moving local features (e.g., trees) are segregated from moving whole objects. Such a system would be likely to segregate self-mobile stimuli (e.g., animals) from the background. This segregation may increase one's awareness and identification of predators and prey. The survival value of this ability is apparent.

In conclusion, the present experiments were a test of the movement filter hypothesis of McLeod et al. (1988). The results of Experiments 1, 2, 3, and 4 indicate that perceptual pop out of a target in a conjunctive display is predicted by the global characteristics of the stimuli. Specifically, moving objects will pop out of a conjunctive display when the motion component is autonomous. However, when the motion component is contained within a static object, pop out does not occur. It is likely that their movement filter operates on the level of the object, not on local features. More experiments are needed to fully understand the interaction between motion types and attention.

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