New indirect measures of “inattentive” visual grouping in a change-detection task

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It has often been suggested that Gestalt-like visual grouping processes may operate preattentively, but Mack and Rock (1998) suggested that no visual grouping takes place under “inattention.” We introduced a new method to assess this. While participants performed a demanding change-detection task on a small matrix at fixation, task-irrelevant background elements were arranged by color similarity into columns, rows, or pseudorandomly. Independent of any change in the target matrix, background grouping could also change or remain the same on each trial. This influenced accuracy of change judgments for the central task, even though background grouping or its change usually could not be explicitly reported when probed with surprise questions as in Mack and Rock. This suggests that visual grouping may arise implicitly under inattention and provides a new method for testing the boundaries of this processing. Here we extended the initial result to changes in background grouping remote from the target and to those occurring across an intervening saccade.

Many authors have proposed that a fundamental task for our visual system is to organize the raw information hitting our retina into coherent groups or “proto-objects” (e.g., see Driver, Davis, Russell, Turatto, & Freeman, 2001; Palmer & Rock, 1994; Wertheimer, 1923). A long-standing debate has concerned the role that attention may play in this organization (e.g., Ben-Av, Sagi, & Braun, 1992; Braun & Sagi, 1990; Driver & Baylis, 1998; Duncan & Humphreys, 1989; Julesz, 1981; Kahneman & Treisman, 1984; Mack & Rock, 1998; Mack, Tang, Tuma, Kahn, & Rock, 1992; Moore & Egeth, 1997; Neisser, 1967; Rock, Linnett, Grant, & Mack, 1992; Treisman, 1982, 1985). Considerable evidence from visual search, plus a variety of so-called “object-based” attention effects, was taken to suggest that visual input may undergo fairly substantial “preattentive” processing, allowing some initial segmentation prior to the direction of attention (e.g., Driver & Baylis 1989; Driver et al., 2001; Duncan, 1984; Duncan & Humphreys, 1989, 1992; Kahneman & Treisman, 1984; Treisman, 1982, 1985). But Mack, Rock, and colleagues (e.g., Mack et al., 1992; Rock et al., 1992) challenged this consensus in the early 1990s. They reported that for situations in which attention may be fully engaged at one location, there might not even be the simplest segmentation for the rest of the visual scene. They argued that interpretations of much previous evidence in terms of supposedly preattentive visual segmentation might have failed to consider the observer’s intention to examine the whole display for a particular

property, as is the case in many visual search tasks (and in some studies of object-based attention; but see Driver & Baylis, 1998). Mack, Rock, and colleagues suggested that many previous experiments might not have measured visual processing truly *without* attention, but rather processing under conditions of diffuse attention.

Mack, Rock, and colleagues (e.g., Mack et al., 1992; Rock et al., 1992) devised a new paradigm to investigate whether processing could occur under what they considered to be true “inattention.” Participants had to make a demanding judgment concerning which arm of a central visual cross was slightly longer. Surrounding this cross was an irrelevant background pattern that could be grouped into various formations according to Gestalt principles. After completing a number of trials of the cross task, participants were suddenly asked a surprise question regarding the grouping of the background pattern on the immediately preceding trial. They were typically at chance (or close to it) as a group in answering these explicit surprise questions. Mack et al. concluded that Gestalt grouping did not take place outside of attention, asserting that “there is *no* perception of either texture segregation or Gestalt grouping under conditions of inattention” (Mack et al., 1992, p. 498). Although subsequent work with variations on the “inattentional-blindness” paradigm introduced by Mack et al. has led to further developments and caveats (e.g., see Mack & Rock, 1998; Simons, 2000a), the initial strong claim about no grouping under inattention appears to have been maintained by at least some authors (e.g., see Mack & Rock, 1998).

The methods and issues introduced by the work of Mack, Rock, and colleagues (Mack et al., 1992; Rock et al., 1992) have proved influential, raising new questions and leading to reconsideration of previous evidence for preattentive processing. But their reliance on retrospective surprise questions as the critical measure can it-

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self be criticized in a number of ways (e.g., see Driver et al., 2001; Moore, 2001; Moore & Egeth, 1997; Moore, Grosjean, & Lleras, 2003). Participants might forget what they had processed in the intervals between initial exposure, subsequent surprise questioning, and eventual report (e.g., see Moore, 2001; Wolfe, 1999; but see also Rees, Russell, Frith, & Driver, 1999). Moreover, visual grouping might proceed under inattention, but only *implicitly*, so that its products are not available for conscious report without attention (e.g., Merikle, Smilek, & Eastwood, 2001; Moore, 2001; but see also Mitroff, Simons, & Franconeri, 2002). Finally, low-confidence knowledge might not be fully assessed with some of the methods used by Mack, Rock, and colleagues, because participants were not always forced to guess the correct answer to the main inattentive grouping question, if they had previously responded that they had seen nothing in the background (e.g., Mack et al., 1992). Given these potential criticisms, it might be useful to devise measures of visual grouping under inattention that are on-line, indirect, and objective, in order to counter the above criticisms and enable measurement of any implicit background grouping under inattention.

Moore and Egeth (1997) conducted a study that sought to fulfill these criteria. While participants judged which of two lines was longer, an array of black dots placed among white dots could be organized into inducers of either the Ponzo or the Müller-Lyer illusion for the target lines. Moore and Egeth found that such arrangements of the task-irrelevant background did indeed produce Ponzo- and Müller-Lyer-like illusions for the target lines and took this as indirect evidence that the background elements had been grouped to form inducers for the illusion. Retrospective surprise questioning of the participants indicated that they could not explicitly report how the background dots had been arranged on the preceding trial, despite this arrangement demonstrably inducing an illusion for the target lines.

Moore and Egeth's (1997) study was important for suggesting more processing of background organization than would be implied by retrospective questioning alone. But some aspects of their method could be open to criticisms that may limit the generality of their conclusions (see also Moore et al., 2003). First, Mack et al. (1992) suggested that to generate a situation of true inattention, the unattended items should not only be task irrelevant but also clearly separate and different from the primary target items (see also, Most et al., 2001). Moore and Egeth's critical background dots were the same color and contrast as the task-relevant lines and were presented very close to them. Proximity to the target has been shown to lead to greater distractor processing within some inattentional-blindness paradigms (e.g., Most, Simons, Scholl, & Chabris, 2000; Newby & Rock, 1998, 2001). Moreover, earlier work also showed that task-irrelevant items may be processed more thoroughly when close to a target (e.g., Eriksen & Eriksen, 1974). It is thus unclear whether the Moore and Egeth conclusion of im-

plicit background grouping under inattention will necessarily generalize to background elements more distant or dissimilar from the target.

The background dots were actually presented so close to one another in Moore and Egeth's (1997) study, and the contrast between the critical black dots and the white dots was so strong, that low-spatial frequency components alone might plausibly have produced dark diagonal inducers for the illusion rather than true Gestalt grouping being required. Finally, the logic of Moore and Egeth's design relied on inducement of a geometric illusion by a diagonal background structure. Although this was ingenious, the specific requirement of inducing an illusion might restrict the range of different types of background grouping for which any inattentive grouping can be indirectly assessed (but see also Moore et al., 2003).

Recent work on the phenomenon of *contextual cuing* (see Chun, 2000; Chun & Jiang, 1998, 2003) has shown that the surrounding background context can influence search performance, even when the effective context cannot be explicitly remembered, but this impressive research was not specifically concerned with Gestalt grouping of the background, and Mack, Rock and colleagues argued that visual search paradigms may not induce inattention for nontarget elements. The present aim was to address their claims about no background grouping under attention, in a paradigm that might circumvent the above criticisms of Moore and Egeth (1997) and that ideally should be generalizable to many situations.

A New Indirect Method for Assessing Inattentive Background Visual Grouping

The new measure to be used here was briefly outlined in a review by Driver et al. (2001, pp. 68–70). The present experiments assess whether change-detection judgments for a small matrix at fixation are affected by any corresponding change (or absence of change) in the grouping of a surrounding, task-irrelevant background configuration.

Note that the use of a change-detection task makes this paradigm of potential relevance to the intriguing phenomenon of *change blindness* (e.g., see Rensink, 2002; Rensink, O'Regan, & Clark, 1997; Simons & Levin, 1997), whereby observers can explicitly fail to detect quite large changes to a visual scene if a salient interruption (e.g., a blank screen) intervenes between the original and changed images. It has been suggested that change blindness may reflect a failure to extract or retain sufficient information across the interruption at unattended regions (e.g., O'Regan, Deubel, Clark, & Rensink, 2000; O'Regan, Rensink, & Clark, 1999; Rensink et al., 1997; Rensink, O'Regan, & Clark, 2000; Simons, 2000b; Simons & Levin, 1997; but see also Shapiro, 2000). The new paradigm we introduce here may have implications for change blindness, in addition to addressing the issue of grouping under inattention that relates to Mack and Rock's (1998) work. Our paradigm also incorporates two sequential displays, separated by a

blank interruption, across which participants must now judge whether a small matrix target stays the same or changes, whereas the task-irrelevant background can independently stay the same or change across the two displays in terms of its grouping and so in principle might produce “congruency” effects on the speed or accuracy of performance in judging whether the target matrix changed. Several other studies have used different methods to assess the possibility of implicit change detection under conditions where observers appear explicitly blind to the change (e.g., Fernandez-Duque & Thornton, 2000; Hollingworth, Williams, & Henderson, 2001; Smilek, Eastwood, & Merikle, 2000; Thornton & Fernandez-Duque, 2000; Williams & Simons, 2000), although this remains controversial (see Mitroff et al., 2002).

Our stimuli consisted of a small black-and-white matrix pattern at screen center, surrounded by 16 background colored circles, in isoluminant red/green or blue/yellow (see Figure 1). The task was to judge whether the target matrix pattern stayed the same or changed slightly across two successive displays, separated by an intervening blank. The background circles were organized into particular configurations by common color (and were thus grouped in terms of a different feature domain to the luminance-defined central matrices). These background configurations could stay the same in their grouping or change across the two successive displays (although individual circles always changed their local color, to avoid reduction of changes in grouping simply to local changes in color; see the General Method section). Change or consistency in background grouping

was independent of whether the central matrix changed or not, thus allowing a congruency manipulation.

Unlike Moore and Egeth’s (1997) study, the present background stimuli were dissimilar to the central targets in color and form and were located farther away from the central target (a point we will examine in more detail in later experiments). The use of grouping by common color, with isoluminant colors, and wider spacing meant that low spatial frequency components were less likely to be responsible for any grouping influence than in Moore and Egeth’s study (especially since parvocellular channels have higher spatial frequency preferences). The background elements were unrelated to the matrix targets in all respects, except for the congruency that was manipulated, allowing us to assess whether any change or otherwise in background grouping might affect change-judgments for the matrix task.

The background elements might therefore satisfy Mack and Rock’s criteria for inattention. To assess this using their own type of measure, we included explicit surprise retrospective questioning at the end of the experiment, similar to that used by Mack, Rock, and colleagues (e.g., Mack & Rock, 1998; Mack et al., 1992; Rock et al., 1992) and also by Moore and Egeth (1997).

To anticipate, we found that changes or otherwise in background grouping produced some congruency effects upon accuracy for the matrix-change task, even though participants usually could not report the nature of background grouping (nor whether or not this had changed) on the preceding trial when probed with explicit surprise questions in the style of Mack and Rock.

Figure 1. Schematic examples of two display sequences in Experiment 1. Background grouping is unchanged in the sequence on the left, but changes from pseudorandom to columnar for the sequence on the right.

This pattern was consistently replicated here across a series of experiments. It shows that processing of changes in task-irrelevant background grouping, as revealed by our new on-line indirect measure, can be more extensive than would be implied by the limited explicit knowledge revealed by surprise direct questioning. This supports and extends Moore and Egeth's (1997) conclusions, while introducing a new method that avoids potential criticism of their work, in a paradigm that can be flexibly applied to many different situations. To illustrate this flexibility, in our final experiment we applied the new method to a transaccadic situation, which provides the first evidence that changes in task-irrelevant background grouping may be implicitly processed even across an intervening saccade that changes the retinal locations of all the stimuli.

GENERAL METHOD

Apparatus and Stimuli

The stimuli were displayed on a Sony Trinitron 12-in. monitor, run on a Macintosh Quadra 610 computer. The task was programmed with VScope software (Version 1.2.5; Enns & Rensink, 1992). The experiment was conducted in a darkened sound-attenuated booth.

Each display consisted of a small centrally presented black-and-white 5×5 grid matrix, similar to those used by Phillips (1974) to assess short-term visual memory, (the whole matrix measured 0.87°), surrounded by an array of 16 colored circles (see Figure 1). The circles each had a diameter of 0.96° and were separated by gaps of 0.91° . All stimuli were presented against a gray background, intermediate in brightness between the black-and-white of the matrix. Two successive displays, separated by an intervening blank, were presented on each trial. The colored circles within each display were grouped by color similarity into two possible configurations. In Experiment 1, they were grouped either into vertical columns or into a pseudorandom pattern with no overall organization (see Figure 1); in a subsequent study, they could be grouped into columns or rows. The two configurations appeared an equal number of times throughout each experiment. The order of these appearances was randomly determined, with the constraint that half the trials involve a change in the background configuration across two successive displays, whereas half did not.

The circles were red and green in the first display, changing to blue and yellow in the second. The red and green colors were iso-luminant (as measured by flicker fusion within the VScope software), as were the blue and yellow, to ensure that any grouping was based on color similarity rather than on differences in luminance; hence the background grouping was defined in a domain different from the luminance-defined matrix target. The constant changes in the colors used from the first to the second display (i.e., from red and green in the first, to blue and yellow in the second, regardless of whether or not grouping changed) should control for the possibility that a change in background organization could be detected from just a few (or even only one) background circles changing their color locally. All circles always changed their local color here, regardless of whether or not their grouping changed. To control for any greater saliency for one form of color mapping versus another (e.g., red changing to blue, vs. red changing to yellow), participants were divided into two groups to counterbalance the mapping. Each of these groups received a different color mapping pattern for the background circles. If the circles remained in the same configuration over both displays, one group (Group A) was presented with red circles changing to blue and green changing to yellow. The other group (Group B) was presented with red changing to yellow and green to blue. During background-change trials (i.e., a change in

organization), color mapping was determined by the color of the top-left circle. This would change to its counterpart color (according to the color-mapping group), and the rest of the circles would change accordingly. Examples of possible color mappings in cases where the background changed are shown in Figure 1. These are the color mappings for Group A; Group B received the reverse.

The central matrix stimuli were based on those used by Phillips (1974) to assess short-term visual memory. Ten 5×5 matrix patterns were created. These original 10 patterns comprised the *same* set of matrices. One of these patterns was randomly selected at the start of each trial and repeated in both the first and second displays for *same* trials during the experiment. For *different* trials, 10 additional matrices were constructed from the original set by changing two cells in each matrix. Within each block, the 10 matrices from the *same* set of stimuli were used at least twice with each of the four permutations of background presentation: same background (columnar–columnar or random–random) or different background (columnar–random or random–columnar). There was an equal probability of the matrix in the second display being the same as or different from the first display.

Design

The experiment used a within-subjects design during the matrix task. Two factors (*central matrix* and *background configuration*) each had two levels. Independently, they either remained the same across the two successive displays of each trial or were *different*. This produced four equiprobable conditions organized into a 2×2 factorial design: same matrix/same background, same matrix/different background, different matrix/same background, and different matrix/different background.

Procedure

The task was to judge whether the second black-and-white central matrix in a trial was the same as or different from the immediately preceding matrix. A trial began with a blank screen presented for 810 msec, followed by a central fixation cross for 750 msec. The first display was then presented for 1,200 msec in Experiments 1 and 2 (reduced to 200 msec in later studies). This was then replaced by a blank screen for 150 msec (thus producing an "interruption" equivalent to those in typical change-blindness studies; e.g., see, Rensink et al., 1997), followed by the second display, which remained on the screen until participants made a keypress response, or for 1,200 msec, followed by the next trials. There were four blocks of 120 trials in the first two studies and then five blocks of 120 trials in later studies, with the possible conditions randomly intermixed in each. The participants were told to pay attention to the central matrix, ignore any other items, and respond as accurately and as rapidly as possible. They viewed the screen from a fixed distance of 87 cm.

Once they had completed four or five blocks of the matrix task, the participants received a final additional block of only eight trials. Following the fourth, seventh, and eighth trials, a set of two questions was presented on the screen. In Experiment 1, the first "surprise" question asked; "Were the circles in the background of the previous display arranged systematically?" Regardless of the answer given to this, for the second question the participants had to make a forced choice between columnar or pseudorandom organization for the preceding display, in response to the prompt: "Regardless of how you answered the previous question, were the circles in the background of the previous display arranged into vertical columns or into a pattern that had no overall organized formation?" The participants were given unlimited time to respond. On the fourth trial in this final block, these questions were entirely unexpected, so they were taken to provide an explicit measure of inattentive background grouping, in the terms of Mack et al. (1992). On subsequent trials, the participants continued making *same–different* judgments for successive matrix stimuli, as before. How-

ever, they were now aware that they might be questioned about the background circles, so the identical two questions after the 7th trial were now seen as a measure of processing with “divided attention” in Mack and Rock’s terms (see Mack et al., 1992; Rock et al., 1992). Finally, on the eighth trial in this final block the participants were told to attend to the background circles in addition to still performing the matrix task, providing a “control” question, again analogous to Mack and Rock.

Correct answers (and thus which preceding display had been shown) for the second explicit question in the final block (i.e., “were the circles in the background of the previous display arranged into vertical columns or into a pattern that had no overall organized formation?”) were counterbalanced across participants. In later experiments, we replaced the questions about the nature of the preceding grouping display with either a visual forced choice between two grouping displays or a written question as to whether “any change” to background grouping had taken place on the previous trial, regardless of its nature.

EXPERIMENT 1

Participants

Twenty-five participants (11 female, 14 male) were recruited by advertisement. Their ages ranged from 17 to 31 ($M = 24$). The participants for this study and all those that follow were paid for participation and were naive about the purpose of the experiment (important because of the surprise retrospective questioning at the end).

Results and Discussion

On-line performance in the matrix task. Table 1 gives intersubject mean error rates and means of median RTs, with standard deviations. Error rate data are also displayed in Figure 2.

Initially, error rates were assessed in a mixed analysis of variance (ANOVA), with the between-subjects factor of color group (Group A vs. Group B) included for completeness, plus the within-subjects factors of matrix (same vs. different) and background configuration (fixed vs. changed). The color group did not interact with target identity [$F(1,23) = .0003$, n.s.] or background configuration [$F(1,23) = .831$, n.s.]. There was no three-way interaction either [$F(1,23) = 1.53$, n.s.]. For simplicity, the error data were therefore pooled across color group in the remaining analyses (and likewise for Experiments 2–5).

In the subsequent two-way within-subjects ANOVA, there was a main effect of matrix type [$F(1,24) = 34.4$, $p < .0001$; responses to *same* matrices were more accurate], and of background configuration [$F(1,24) = 25.9$, $p < .0001$; responses were more accurate when background changed]. Critically for the issue of any congruency effects, these two factors interacted [$F(1,24) =$

23.7, $p < .0001$]. Comparisons of means revealed that responses on trials where the matrix changed contributed to this interaction. The participants were more accurate on different-matrix trials when the background grouping also changed rather than when it remained the same [$F(1,24) = 61.3$, $p < .0001$]. There was no analogous effect in the trials where the matrix was unchanged [$F(1,24) = 0.8$, n.s.; see Figure 2].

The RT data were also initially examined in a mixed ANOVA to assess whether the two color-mapping groups showed different or similar patterns. There were no significant influences of color group. Neither matrix identity [$F(1,23) = .0004$, n.s.] nor background configuration [$F(1,23) = .065$, n.s.] interacted with color-mapping group, and there was no three-way interaction [$F(1,23) = .726$, n.s.]. The data were therefore pooled across color group to simplify subsequent analyses (and likewise for all subsequent RT analyses in this article).

A two-way within-subjects ANOVA on RT data demonstrated no main effect for matrix type [$F(1,24) = 0.39$, n.s.] or background configuration [$F(1,24) = 0.001$, n.s.], but the interaction between these factors approached significance [$F(1,24) = 3.9$, $p = .058$]. Planned comparisons suggested that this trend was due to a tendency for faster responses to a *different* matrix when the background also changed [$F(1,24) = 3.9$, $p = .064$], which is consistent with the significant congruency effect for this situation in the error data.

Responses to the Mack and Rock surprise retrospective questions. Only 12 participants (48%) correctly answered the first inattentive question and likewise for the second (i.e., open description, and then forced choice). This level was not above chance. For the two divided attention questions, 12 (48%) and then 15 (60%) participants answered correctly for the first and second questions, respectively, again no greater than chance. By contrast, 18 participants (72%) were correct for both *control* questions, now significantly above chance [$\chi^2(1) = 4.84$, $p < .05$ for both] when told to attend to the background configurations, while completing the matrix task.

Summary of results for Experiment 1. Responses to a change in the central matrix were more accurate (and tended to be faster) when the unrelated background changed its grouping on the basis of color similarity. This suggests that the background organization undergoes more processing than one would have inferred, following Mack and Rock’s (1998) logic, from the overall chance level of accuracy in response to surprise explicit questions about background organization under inattention.

It thus seems that at least some processing of task-irrelevant background grouping, and of any change in this grouping across an interruption, must have taken place. One potential problem with Experiment 1, however, is that instead of performance reflecting grouping of the *whole* background, participants might be affected merely by any change in organization for those four circles that directly surrounded the central matrix (i.e.,

Table 1
Mean Error Rates and Means of Median RTs
(With Standard Deviations) in Experiment 1

	Matrix	Background Organization	
		Same	Different
ER (%)	Same	6 (4)	6 (5)
	Different	14 (4)	9 (4)
RT (msec)	Same	722 (221)	728 (91)
	Different	733 (205)	718 (196)

Figure 2. Mean error rate data for Experiment 1. The scale was chosen to facilitate comparison with Experiments 2–5.

those nearest the center and most proximal to the target). When the organization of the entire background changed, the organization of these four circles also changed correspondingly (see Figure 1). Participants may not have been aware of these changes (consistent with their poor responses to surprise explicit questions) but might nevertheless have implicitly extracted a change in organization for just those background circles that were closest to the central matrix, leading to some congruency effect without entailing inattentive grouping of the *entire* background display. As discussed earlier, it may be important when addressing inattentive processing to consider items that are not immediately adjacent to task-relevant targets. For instance, Most et al. (2000) reported that unexpected items closer to the current focus of attention are less likely to suffer from inattentive blindness than are those farther away (see also Eriksen & Eriksen, 1974; Newby & Rock 1998, 2001).

The next experiment addressed this potential criticism. The organization of the background circles was now altered such that the central four circles, adjacent to the central matrix, never changed their organization, even when the overall grouping of the background changed. Figure 3 gives an example of how the new background displays made this possible.

EXPERIMENT 2

Participants

Twenty-eight new participants (15 female, 13 male) were recruited. Their ages ranged from 18 to 31 ($M = 24$).

Results and Discussion

On-line performance in the matrix task. Table 2 gives the error rates, means of median RTs (and standard

deviations). Figure 4 plots the intersubject mean error rates.

A two-way within-subjects ANOVA on error rates revealed main effects of matrix [$F(1,27) = 28.9, p < .0001$] and background configuration [$F(1,27) = 50.6, p < .0001$]. Again, these main effects were due to greater overall accuracy for responses to *same* matrices and during *different* background formats. More important, there was also a significant interaction between matrix type and background configuration [$F(1,27) = 39.2, p < .0001$], indicating some congruency effect. Means comparisons revealed that this again reflected greater accuracy in responding to a changed target matrix when the background also changed [$F(1,27) = 103.2, p < .0001$; see Figure 4].

Reaction times were analyzed in the same way. The two-way within-subjects ANOVAs revealed no main effect of matrix format [same vs. different; $F(1,27) = .363, n.s.$] nor of background configuration [fixed vs. changed; $F(1,27) = 3.35, n.s.$]. The interaction between matrix type and background was also insignificant [$F(1,27) = 2.39, n.s.$]. But the RT pattern for responses to *different* matrices did not suggest that the significant result for these matrices within the accuracy data was due to a speed–accuracy tradeoff for this condition (see Table 2).

Responses to the Mack and Rock surprise retrospective questions. Responses to the two *inattentive* explicit questions were not above chance; only 16 participants (60%) correctly answered the first question, whereas 12 (48%) correctly answered the second. Responses during divided attention approached significance [$\chi^2(1) = 3.6, p = .06$ for both questions] since 19 participants (68%) were correct in these. Participants were significantly above chance for the final *control* questions [$\chi^2(1) =$

Figure 3. Schematic example of a trial from Experiment 2. The front panel demonstrates in close-up the new pseudorandom organization of colored circles that enabled the four circles adjacent to the matrix pattern to be unchanged in organization throughout the experiment.

14.3, $p < .0001$; $\chi^2(1) = 9.1$, $p < .0001$], with 24 (86%) and 22 (79%) participants correctly answering the first and second questions, respectively.

Summary of results for Experiment 2. As in Experiment 1, detection of small changes in the central matrix was more accurate when grouping of task-irrelevant background circles by common color also changed. A between-experiments analysis confirmed that this effect was in fact equivalent between the two experiments [all $F_s(1,51) < 0.18$, n.s.], in a three-way mixed ANOVA. Thus, changing the background grouping still influenced on-line performance in the matrix task, even when the change in background grouping no longer applied to those background elements adjacent to the central matrix. Moreover, the congruency effect from changes in background grouping arose once again even though participants still remained at chance in responding to explicit surprise questions about the nature of the background organization.

A possible limitation of the experiments thus far concerns the rather lengthy presentation time (1,200 msec) for the first experimental display on each trial. This might increase the possibility of participants inadvertently attending to or even shifting their eyes toward some background elements. The next experiment examined whether decreasing the duration of the first display to just 200 msec would eliminate the congruency effect. These briefer

displays might increase the difficulty or “perceptual load” of the matrix task, which can eliminate some types of distractor processing (e.g., Lavie, 1995). The question here was whether changes or otherwise in background grouping would still influence matrix judgments even with the much briefer initial display.

EXPERIMENT 3

Participants

There were 24 new participants (12 female, 12 male). Their ages ranged from 19 to 33 ($M = 23$).

Results and Discussion

On-line performance in the matrix task. Table 3 gives mean error rates and means of median RTs for each condition, with standard deviations. Figure 5 plots the error data graphically.

Table 2
Mean Error Rates and Means of Median RTs
(With Standard Deviations) in Experiment 2

		Background Organization	
		Same	Different
ER (%)	Same	11 (6)	10 (6)
	Different	20 (7)	14 (8)
RT (msec)	Same	742 (157)	728 (148)
	Different	730 (143)	728 (145)

Figure 4. Mean error rate data for Experiment 2.

A two-way within-subjects ANOVA on errors revealed a main effect for matrix type [$F(1,23) = 62.2, p < .0001$], with higher accuracy for unchanged matrices and for background configuration [$F(1,23) = 11.5, p < .005$], with higher accuracy when the background changed. Critically, there was also a significant interaction [$F(1,23) = 7.7, p = .011$]. Planned comparisons revealed that this was again due to more accurate responses to changed matrices when background grouping also changed [$F(1,23) = 17.420, p < .001$], as in the preceding two studies (see Figure 5 and cf. Figures 2 and 4).

Analysis of RT data revealed no significant effects. There was no effect of target matrix [$F(1,23) = .72, n.s.$] or background configuration [$F(1,23) = 1.2, n.s.$], and the two factors did not interact [$F(1,23) = 3.1, p > .05$].

Responses to the Mack and Rock surprise retrospective questions. Only 12 participants (50%) correctly answered the first *inattentive* question, and only 10 (42%) were correct for the second *inattentive* question, no better than chance. Sixteen participants (67%) answered correctly each of the *divided attention* questions [$\chi^2(1) = 2.7, n.s.$]. For the final *control* questions, performance was now above chance [$\chi^2(1) = 4.2, p < .05$, and $\chi^2(1) = 8.3, p < .01$], whereas 17 (71%) and 19 (79%) were correct for first and second questions, respectively.

Summary of results for Experiment 3. The overall pattern in Experiment 3 is strikingly similar to that found previously in Experiments 1 and 2, with significantly more accurate responses to a changed central matrix when the task-irrelevant background grouping also changed, even though explicit responses concerning the background grouping were still at chance overall on surprise direct questioning under inattention. To assess the similarity of matrix-task results for Experiments 2 and 3, we ran a mixed ANOVA on error data. Experiment interacted with matrix type [$F(1,50) = 10.663, p < .01$], due

to worse accuracy in Experiment 3, particularly for changed matrices (cf. Figures 4 and 5), presumably reflecting the greater difficulty of detecting matrix changes when the first matrix was much briefer. More important, the between-subjects factor of experiment did not interact with background conditions [$F(1,50) = .099, n.s.$], and there was no three-way interaction [$F(1,50) = .010, n.s.$]. Hence, the impact of background grouping on matrix accuracy was equivalent for Experiments 2 and 3, despite the substantial reduction in display duration for the latter.

The results of our initial experiment have now been replicated and extended twice. But the two possible grouping arrangements in all these experiments were columnar or *disorganized*. To assess whether similar results would be found for changes between two different forms of *organized* grouping, in a further study (not reported in full here for brevity), the background could now be organized into columns or rows only (all other details were the same as in Experiment 1). The critical congruency effect in the matrix task was replicated once again, in 20 new participants with row versus column grouping.¹ So the pattern of findings applies for both changes from organized into disorganized grouping and also between two different forms of grouping (row vs. column).

Table 3
Mean Error Rates and Means of Median RTs
(With Standard Deviations) in Experiment 3

	Matrix	Background Organization	
		Same	Different
ER (%)	Same	9 (7)	9 (7)
	Different	24 (8)	19 (8)
RT (msec)	Same	547 (134)	542 (99)
	Different	546 (128)	548 (100)

Figure 5. Mean error rate data for Experiment 3.

EXPERIMENTS 4A AND 4B

The above experiments consistently showed the same pattern of results, despite variations introduced to the displays for the matrix task (specifically to display duration and to the nature of the possible background organizations). In the next two studies, we now instead varied just the exact nature of the direct questions in the final retrospective question block. In all of the preceding experiments, these direct questions were presented in written form on the screen. In Experiment 4A, we now instead gave participants a visual forced-choice decision between two visually presented grouping displays, requiring them to choose which most closely resembled the preceding background display.² As will be seen, this potentially more sensitive measure of any knowledge about the preceding background display still yielded performance no better than chance on direct test under inattention.

In Experiment 4B, we returned to written direct questions, but now instead of asking participants to report the nature of background grouping from the preceding display that had ended the previous trial, we asked them to report whether or not there had been *any change* in background grouping across the two displays in the preceding trial (since, after all, the presence or absence of such change could have produced the congruency effects on matrix judgments).³ As will be seen, this new form of questioning also led to poor performance on direct questioning under inattention.

EXPERIMENT 4A

This study repeated the methodology of Experiment 3 for the first five blocks of the matrix task. The final question block was altered to include pictorial representations of the possible background configurations. There was now only one question for each of the three condi-

tions within the question block (i.e., inattentive, divided attention, and control). Pictures of the two possible background configurations were displayed simultaneously side by side on the screen and participants were asked to press a corresponding button to indicate which pattern they thought might have been presented as the background in the preceding display, in a forced-choice procedure.

Participants

Twenty new naive participants (13 female, 7 male) were recruited. Their ages ranged from 19 to 27 ($M = 22$).

Results and Discussion. The first five blocks were analyzed as before. Error data revealed a main effect of matrix condition, with *same* matrices responded to more accurately [$F(1,19) = 26.25, p < .0001$] than different matrices. There was also a main effect of background condition, with more accuracy when the background changed [$F(1,19) = 6.1, p < .05$]. More important, there was again a significant interaction between these two factors [$F(1,19) = 37.10, p < .0001$]. Planned mean comparisons again showed that participants were more accurate to respond to *different* target matrices when the background configuration also changed [11% vs. 15%; $F(1,19) = 37.19, p < .0001$]. For the first time, they were also more accurate in responding to *same* matrices when background grouping remained the same [5% vs. 7%; $F(1,19) = 6.37, p < .05$] although this effect was smaller. In RT data, the only significant result was a main effect of target matrix condition [$F(1,19) = 11.59, p < .01$], with *same* matrices responded to faster. Thus, matrix performance again showed an influence of background grouping on accuracy.

Answers in the question block revealed that, despite the change to forced-choice visual discrimination, knowledge of background grouping on direct questioning under inattention was still no better than chance. Only 5 par-

ticipants (25%) correctly answered the inattentive question. The number of correct answers increased to 14 (70%) for the *divided attention* situation and to 15 (75%) for the *control* question.

Experiment 4B

The first five blocks were again identical to Experiment 3 (and 4A), but the question block now gave participants written questions (on the screen) about whether they had detected *any change* in the background organization across the two displays that composed the preceding trial. Again, there was now just one question for each condition (i.e., inattentive, divided attention, and control).

Participants

Twenty-one new participants (16 female, 5 male) were recruited. Their ages ranged from 18 to 27 ($M = 20$).

Results and Discussion

Data for the first five blocks were analyzed as before. For the error data, there was a main effect of target, with responses to *same* matrices more accurate [$F(1,20) = 7.04, p < .01$], and a main effect of background, with responses during different-background trials more accurate [$F(1,20) = 12.18, p < .001$]. More important, these two factors again interacted [$F(1,20) = 34.08, p < .0001$]. Responses to *different* matrices were significantly more accurate when the background organization also changed [11% vs. 16%; $F(1,20) = 38.11, p < .0001$], but there was no such effect of different- versus same-background organization for *same* matrices (7% vs. 8%). In RTs, the only significance was a main effect of matrix type, in which *same* matrices were responded to faster [$F(1,20) = 5.27, p < .05$]. Thus, results from the first five blocks neatly replicate the congruency effects on matrix accuracy consistently shown in earlier experiments.

Turning to the critical new question block, asking participants whether the background organization had undergone any change on the preceding trial did not appear to alter the degree of information available for explicit report under *inattentive* conditions. Only 10 participants (48%) correctly answered the first question. Performance was no better than chance in explicitly reporting any change in background grouping, even for the subsequent *divided attention* (38%) and *control* (52%) questions. This presumably reflects the greater difficulty of explicitly judging changes in grouping (vs. the nature of grouping in a single display, as in our previous experiments). It again contrasts with the reliable congruency effect from changes in background grouping on the indirect measure during the matrix task.

This series of consistent congruency results from changes in background grouping suggests that at least some processing of background grouping (possibly implicit) can arise even under conditions that appear to satisfy Mack and Rock's criteria for inattention, in which

participants respond poorly to direct questioning about the grouping or any change in it for the preceding display. Moreover, the effective changes in background grouping arose across a visual interruption (here, a brief blanking of the screen, as in many change-blindness studies), suggesting that our new paradigm may be useful for providing an indirect measure of processing for background changes that may not be explicitly detected.

EXPERIMENT 5

Extension to a Transsaccadic Situation

A major aim of the present article was to devise a new paradigm for indirectly probing whether changes to background grouping may be processed to some extent outside the focus of attention. Moreover, we sought to develop a paradigm whose general logic might be applicable to many different situations (e.g., not just to geometric illusions of the type studied by Moore & Egeth, 1997). To illustrate the flexibility of the present paradigm, in our final experiments we applied it to a transsaccadic situation in order to assess whether changes in background grouping might be extracted even across intervening saccades that always shifted the retinal locations of all background elements.

Research into saccadic eye movements may overlap with attention research. Saccades clearly provide one important overt mechanism for spatial orienting and visual selection. Moreover, control of overt saccades and of covert spatial attention may involve partially overlapping neural networks (see, e.g., Corbetta et al., 1998; Kustov & Robinson, 1996). Finally, some authors have suggested attentional causes for apparent restrictions of transsaccadic integration (e.g., Irwin, 1992; Irwin & Andrews, 1996; Irwin, Zacks, & Brown, 1990; Rensink et al., 1997), arguing that only attended information may be brought forward across visual interruptions such as those induced by shifts in eye position (analogous to similar arguments that only attended information may be maintained in change-blindness studies; see Rensink et al., 1997).

Studies of perceptual processing across saccades have produced many intriguing results. Although it was initially thought that visual information from one fixation might be globally integrated with spatially displaced information from the subsequent fixation (e.g., Jonides, Irwin, & Yantis, 1982), it has more recently been suggested that very little information may actually be carried forward from the previous fixation (e.g., Blackmore, Brelstaff, Nelson, & Troscianko, 1995; Currie, McConkie, Carlson-Radvansky, & Irwin, 2000; Grimes, 1996; Irwin et al., 1990; Jonides, Irwin, & Yantis, 1983; McConkie & Currie, 1996; McConkie & Zola, 1979; Pollatsek, Rayner, & Collins, 1984; Pollatsek, Rayner, & Henderson, 1990; Rayner, 1992). However, many studies that reported minimal integration across saccades relied solely or primarily on explicit measures or direct questions (but see Hayhoe, Bensinger, & Ballard, 1998; Hen-

derson & Hollingworth, 2003; Hollingworth & Henderson, 2000; Hollingworth, Schrock, & Henderson, 2001; Hollingworth, Williams, & Henderson, 2001). For instance, Currie et al. (2000) demonstrated that a small spatial displacement of a "saccade target object" was detected explicitly much better than was displacement of the entire background behind the target object, or even of the whole image, with the latter two types of change often not detected by the participant. However, these authors used only participants' *explicit* detection of change to assess transsaccadic processing, thus potentially overlooking the possibility that background changes might have been processed implicitly yet remained inaccessible to awareness (see Hayhoe et al., 1998; Henderson & Hollingworth, 2003; Hollingworth & Henderson, 2000; Hollingworth, Schrock, & Henderson, 2001; Hollingworth, Williams, & Henderson, 2001).

Although such findings suggest that observers may have little explicit awareness of any background changes that arise during a saccade, some types of background change might still be extracted implicitly (as apparently for the changes in background grouping studied here), even when arising across a saccade. Here, we examined this for the changes in background grouping that were used in the preceding experiments, but now in a situation where a large saccade intervened between the small matrices that had to be compared, and thus also between the background displays whose grouping by common color could change or remain the same.

Instead of always presenting the small target matrix at screen center as before, we now presented it predictably at a far-left location in the first display, and then at a far-right location (where a preceding place-marker appeared) in the second display. Pilot work confirmed that comparison of the patterns in the small successive matrices (to determine whether or not a matrix change had occurred) could *not* be performed unless participants made the desired sequence of left-then-right fixations. In other words, they had to fixate at the correct location ahead of each brief matrix presentation in order to resolve the pattern within each matrix—first fixating at the far left of the display until the first matrix appeared and then fixating the place-marker at the far right ahead of the second matrix. In this way, we were able to enforce a large lateral saccade between successive matrix/background displays, without requiring saccade-contingent displays to be initiated by eye-tracking data.

Our new question was whether change or stability in task-irrelevant background grouping, under conditions that should satisfy Mack and Rock's criteria for inattention, would still influence performance in the matrix change-detection task, even when a substantial saccade now intervened between the two successive displays on each trial (thus always shifting the retinal location of every background element, regardless of whether grouping changed). Regarding Currie et al.'s (2000) proposal that background information is simply not integrated

across saccades, no such effect should arise. But it is possible that any changes in task-irrelevant background grouping might be extracted implicitly (consistent with our previous experiments here) and that this may arise even across a substantial saccade.

Method

Participants. Twenty-four new participants (17 female, 7 male) were recruited. Their ages ranged from 18 to 28 ($M = 22$).

Apparatus and Stimuli. This experiment used a Power Macintosh G3 computer programmed with PsyScope 1.2.5 software (Cohen, MacWhinney, Flatt & Provost, 1993). The display monitor was identical to that of the previous studies, and the experiment took place in a darkened, sound-attenuated booth.

Exactly the same matrix patterns and the same size, positions, and colors of background circles were used as before. But the viewing distance was now slightly shorter (80 cm, due to a change in laboratory), so visual angles were somewhat different. The small black-and-white matrices were now 0.95° , the diameter of the circles was 1.05° , and the gaps between circles were 0.99° . In order to assess whether changes or otherwise in background grouping by common color could be extracted across a saccadic eye movement, several further important changes were implemented. First, the small black-and-white matrix patterns were no longer presented at screen center. In the first display, the matrix now appeared on the horizontal screen meridian, but 0.6° to the *left* of the leftmost column of circles and thus at 4.7° to the left of screen center. In the second display, a small black-and-white matrix now reappeared (still on the horizontal screen meridian) at 0.6° to the *right* of the rightmost circle column and thus at 4.7° to the right of screen center. See Figure 6 below for a schematic layout of the stimuli in two successive displays, separated by an intervening blank as before, but now also by an intervening saccade of approximately 11° from left (marked location of first matrix) to right (marked location of second). The initial fixation cross was now presented in the same position as the center of the first matrix pattern (i.e., at the far left of the display).

Initial piloting indicated that the matrix task became extremely difficult with the shift in position across successive displays, unless the location of the second matrix was marked in advance to provide a saccade target before onset of the second matrix. Accordingly, in order to guide the saccade from the left matrix to the subsequent right matrix in advance, a black frame the same size as a matrix pattern was placed at the position of the second matrix during the blank period between displays (see Figure 6). The predictable sequence of the required fixations (left then right for every trial), together with the visible landmarks, made the required saccade clear and allowed accurate performance in the matrix comparison (see below), which was not possible without a saccade, as confirmed in piloting.

As mentioned earlier, the individual background circles remained the same as in previous experiments, with the same positioning and possible colors. However, the background dots were now grouped by color similarity into vertical columns or *horizontal rows* (see Figure 6; see also the previous study mentioned in note (1)). Circles still changed color in every trial (from red and green in the first display to blue and yellow in the second), regardless of whether grouping changed. Color mapping was again counterbalanced across participants.

This experiment thus sought to test whether changes in background grouping can still influence matrix performance even when a substantial saccade intervenes. Note that in doing so, it also tested whether any such influence can still arise even when all background circles always changed retinal location between the first and second display on each trial (even when grouping did not change). The results should thus reveal whether the influence of different versus

Figure 6. Example of a possible trial from Experiment 5. Note that the circles and matrices were similar to those of the previous experiments, except that the first small black-and-white matrix now appeared at the far left and the second at the far right (in the location marked during the intervening blank).

same background grouping can generalize not only across the interruption introduced by a saccade, but also across the associated shift in retinal location for all background elements.

Procedure. The participants' instructions regarding the matrix task were similar to those in the previous experiments. They were again told to respond as accurately and quickly as possible in judging whether the target matrix had changed across the course of the two successive displays in each trial. The instruction to ignore anything on the screen apart from the small target matrices was repeated. Additional instructions explained to them the need to follow, with their eyes rather than with a head movement, the shift in position of the small black-and-white matrix from the far left to the far right of the screen (to the position marked by the blank outline square).

We used the same timing of experimental events as in Experiment 3. Due to the greater difficulty of Experiment 5 (due to the shift in matrix location), participants were given practice with 24 randomly chosen trials before starting the main experiment. This also gave the experimenter a chance to check by observation that they were performing the task correctly—for example, not moving their head to follow the target but reliably saccading from left to right.

As in previous studies the final additional block presented surprise explicit questions after the fourth, seventh and eighth trials. Each set of questions was similar to those used in Experiments 1–3, except, due to the columnar versus row formations, the second question of each set now asked, “Regardless of how you answered the previous question, were the background circles arranged into vertical columns or horizontal rows?”

Results

On-line performance in the matrix task. Table 4 shows the numerical means and standard deviations for error and RT data. Figure 7 graphs the error rate data for this experiment.

Error data were analyzed in a two-way within-subjects ANOVA. There was a main effect of target matrix type [$F(1,23) = 4.7, p < .05$], with responses to matrices that changed now being more accurate (unlike in the previous experiments, as we discuss below). However, there was no main effect of background organization [$F(1,23) = 1.5, n.s.$]. Critically, these two factors significantly interacted once again [$F(1,23) = 4.3, p < .05$] because when the target remained the same, participants were

Table 4
Mean Error Rates and Means of Median RTs
(With Standard Deviations) in Experiment 5

	Matrix	Background Organization	
		Same	Different
ER (%)	Same	13 (8)	18 (9)
	Different	18 (10)	17 (8)
RT (msec)	Same	580 (118)	585 (120)
	Different	614 (102)	611 (104)

Figure 7. Mean error rate data for Experiment 5.

significantly more accurate when the background grouping also remained the same [$F(1,23) = 5.797, p < .05$] while there was no such effect of background status within responses to the different matrices [$F(1,23) = 0.279, n.s.$]. Note that whereas the congruency effect thus took a form somewhat different from the previous experiments (with the main result now being that unchanged background grouping facilitated the accuracy of “no-change” judgments for the matrix, rather than changed background grouping facilitating the accuracy of “change” judgments for the matrix as in earlier experiments), the critical point nevertheless remains that a significant congruency effect of some form was found (as shown by the interaction and its source), with background grouping across the two displays again affecting the accuracy of matrix performance, despite the intervening saccade. Below, we discuss the possible reasons for the change in the exact nature of the congruency effect on accuracy.

RT analysis revealed a main effect of matrix type [$F(1,23) = 24.5, p < .0001$], with faster responses when the matrix stayed the same, but no effect of background organization [$F(1,23) = .089, n.s.$]. There was no interaction between the two factors [$F(1,23) = 1.83, n.s.$].

Responses to the Mack and Rock surprise retrospective questions. Data from two participants were lost due to computer failure, leaving data available from 22 participants. χ^2 analysis demonstrated that they were above chance in answering the first inattentive question about whether or not the background was organized regularly [18 participants out of 22 correct, 82%; $\chi^2(1) = 8.909, p < .01$], but not in answering the second question about whether the organization on the preceding trial was rows or columns [14 correct, 64%; $\chi^2(1) = 1.636, n.s.$]. Participants were again above chance for the first question under divided attention conditions [17 participants, 77%; $\chi^2(1) = 6.545, p < .01$] but not the second

[13 correct, 59%]; $\chi^2(1) = .727, n.s.$]. Finally, 16 participants (73%) were correct for the first control question, resulting in an above-chance performance [$\chi^2(1) = 4.545, p < .05$], but only 14 (64%) were correct when specifying the grouped pattern, which was not above chance [$\chi^2(1) = 1.636, n.s.$]. Thus, participants failed to correctly answer even the final control question at above-chance levels. We suggest that this arose because completing the matrix task (which was still performed for the trial with the control question) with an intervening saccade may be so demanding as to effectively prevent high levels of explicit processing for the background, even when participants were told to attend to this region in addition to performing the matrix task. The poor performance on explicit questions about row-versus-column grouping here contrasts, of course, with the reliable congruency effect found from background grouping on the indirect measure of matrix accuracy.

Discussion of Experiment 5

These results indicate that at least some information about the grouping of the background circles, whether or not this grouping remained the same, may be preserved even across a saccadic eye movement, at least implicitly, as revealed by the congruency effect on the error data in the matrix task. This implies that participants must, to some extent, process and preserve information about the task-irrelevant organization of the circles across the two fixations required in each trial of the matrix task.

The pattern of congruency results for this experiment was somewhat different compared with those of the preceding three experiments. Whereas previously, the most consistent congruency effect concerned greater accuracy for a changing matrix when the background configuration also changed, here participants were significantly more accurate when responding to *same* matrix targets when background grouping also remained the same. In

the previous experiments, responses to *same* matrices were always more accurate than to different matrices, whereas the reverse was true here. *Same* judgments may now have been more difficult because the matrices were now always *different* in terms of their location. The change in location for the matrix within each trial of the present experiment may have lead to some default tendency to respond "different" rather than "same," effectively reversing which response is "marked" (e.g., in the previous experiments, it may have been matrix change that was treated as the property to be detected, whereas with the shift in location matrix similarity may have become the property to be detected). This potential change in which response category was marked might in principle explain the changed pattern of congruency effects. Although this is speculation, the important point remains that a reliable congruency effect was observed nonetheless, thus indicating some processing of whether or not background grouping changed even across a saccade.

If we turn to the explicit retrospective questions, there was a relatively high percentage of correct answers for the first inattentive question within this experiment. This might be due to the fact that both background formats were now always "systematically arranged" (into either columns or rows); a similar pattern was also seen in the control study mentioned in note 1. But it still seems clear that no above-chance explicit knowledge was available about the exact nature of the background organization (i.e., grouped into rows vs. columns here), since in the second inattentive question participants were at chance overall when attempting to report the previous display's arrangement. In fact, it appears that explicit knowledge of the row-versus-column grouping of the background circles remained poor in the present study even when participants were told in advance to attend to this region if they could while also performing the matrix task (in the trial prior to the final set of questions in the question block). The requirements to execute a saccade and compare matrices at different positions may explain why explicit knowledge was lacking even for the control question in the present study.

Experiment 5 thus provides initial evidence that visual grouping for a task-irrelevant background may be extracted—and some information about this grouping brought forward, even transaccadically—from one fixation to the next. This processing for row-versus-column background grouping does not necessarily seem accessible to explicit knowledge, since it was not apparent on direct questioning and instead might operate only implicitly. This suggests that many previous experiments could have underestimated transaccadic processing when relying solely or primarily on explicit measures (e.g., see Currie et al., 2000; McConkie & Currie, 1996; see also Hayhoe et al., 1998; Hollingworth & Henderson, 2000; Hollingworth, Schrock, & Henderson, 2001; Hollingworth, Williams, & Henderson, 2001, for further examples of implicit transaccadic effects, albeit not concerned

specifically with background grouping). Finally, the present experiment illustrates the flexibility of the paradigm we have introduced by extending it to a transaccadic situation.

GENERAL DISCUSSION

The central aim of our experiments was to develop a new indirect method for examining background grouping under conditions meeting Mack and Rock's (1998) criteria for inattention. We sought to circumvent some of the limitations of previous paradigms and to devise a new method that, once established, might then be adaptable in future work to examine different types of grouping and different attentional or saccadic conditions.

Grouping Under Inattention

Our experiments provide converging evidence that at least some visual grouping of task-irrelevant background elements (here by common color) may arise under conditions of inattention. Throughout the experiments, participants' performance in a matrix-comparison task was influenced by change or continuity in the organization of task-irrelevant background circles. This arose although participants exhibited little or no explicit knowledge of background organization when tested in the Mack and Rock fashion with surprise explicit questions, with a visual forced choice, or when asked about any change to background organization. These results remained consistent when changes in the background organization were moved further from the focus of attention and when presentation time was decreased. Furthermore, the use of vertical versus horizontal grouping in an additional study plus Experiment 5 revealed that these results were not specific to changes from ordered to pseudorandom background grouping patterns. A congruency effect was still evident for changes between two ordered forms of background grouping.

These results suggest that there can be processing of background grouping (by common color) under conditions that appear to satisfy Mack and Rock's (1998) criteria for inattention. Mack and colleagues had based their initial conclusions solely on what *inattentive* participants could *explicitly* reveal retrospectively in response to surprise questions. Such explicit questions within the present paradigm confirmed that our participants performed much like those in Mack and Rock's studies (Mack & Rock, 1998; Mack et al., 1992; Rock et al., 1992), seemingly unaware of the exact nature of the grouping pattern from the preceding display when this processing was assessed by surprise explicit questioning, despite the consistent congruency effects observed on the indirect measure of matrix performance.

Mack and Rock (1998) themselves recently altered their previously stringent position on inattentive processing. They now concede that some *implicit* processing of unattended stimuli may take place, having carried

out some studies using an indirect method to measure implicit method under inattention (specifically, stem-completion of words, and whether this can be primed by a previously unattended word; see Mack & Rock, 1998, pp. 175–191). However, Mack, Rock, and their colleagues have not, to our knowledge, assessed implicit processing specifically for *visual grouping*, as has been done here. Moreover, as Moore (2001) points out, they apparently did not entirely change their position with respect to visual grouping in light of their own priming studies, since their book (Mack & Rock, 1998, p. 34) still states: “result[s] would appear to underscore the conclusion that these kinds of grouping, which for so long have been assumed to occur automatically—that is, preattentively, in fact require the active engagement of attention.” Of course, this statement may have been intended to refer to explicit (conscious, phenomenal) grouping, whereas our own conclusions may refer to grouping processes that operate implicitly.

Our results support and extend the studies of Moore & Egeth (1997; see also Moore, 2001; Moore et al., 2003). The present paradigm avoids several potential criticisms of their study. The task-irrelevant background elements here were dissimilar to the target matrix not only in location, but in color and shape, whereas grouping was defined in a different domain (isoluminant color) from that which defined the task-relevant targets (the luminance-defined matrices).

Implicit Measures of Change Detection

Standard measures of *explicit* change detection across brief interruptions have generally led to conclusions that changes can remain undetected when falling outside the focus of attention (e.g., O’Regan et al., 2000; Rensink et al., 1997, 2000). However, the present experiments suggest that whereas the nature of background grouping, and of any changes in it, may not have been *explicitly* available, these were nevertheless processed to some degree, since change or continuity in background grouping did produce congruency effects on accuracy for the target matrices. This aspect of our findings may accord with some other studies suggesting possible implicit change detection within change-blindness paradigms (e.g., Fernandez-Duque & Thornton, 2000; Smilek et al., 2000; Thornton & Fernandez-Duque, 2000; Williams & Simons, 2000), although such previous evidence has recently been contested (see Mitroff et al., 2002). It might still be suggested that explicit knowledge was somehow underestimated here, perhaps due to rapid or instantaneous forgetting, or to interference in memory from preceding trials. But the main aim of our article was to develop a new method to assess processing of task-irrelevant background grouping with an on-line measure, and in this we seem to have succeeded. It may be for future research to refine measures of explicit knowledge beyond the variety of direct questions and visual forced choice that were used here.

Indirect Measures of Processing of Backgrounds Across Saccades

Experiment 5 adapted the new methodology to study whether task-irrelevant background grouping may be processed *and brought forward* even across an intervening saccade. Results revealed that grouping of the task-irrelevant background items must indeed have been extracted, and carried forward to some extent, across the saccade that intervened between the two successive displays, since a congruency effect from background grouping was produced on error rates in the matrix task. This result implies some sensitivity to whether the grouping of the background elements changed or not, even when all these elements always shifted their retinal location between successive displays, regardless of grouping. Many previous studies have suggested that very little background processing is integrated across saccades (e.g., see Blackmore et al., 1995; Currie et al., 2000; Grimes, 1996; McConkie & Currie, 1996). However, these studies often relied on explicit detection of change (but see also Hayhoe et al., 1998; Henderson & Hollingworth, 2003; Henderson, Pollatsek & Rayner, 1987; Hollingworth & Henderson, 2000; Hollingworth, Schrock, & Henderson, 2001; Hollingworth, Williams, & Henderson, 2001). Furthermore, many studies examining transsaccadic processing may have effectively compared processing of attended items versus unattended items across a saccade (e.g., see Carlson-Radvansky & Irwin, 1995; Currie et al., 2000; Irwin, 1992; Irwin & Andrews, 1996). Much previous work on transsaccadic integration may have involved attentional factors, and unattended processing can clearly be underestimated by direct explicit measures, as compared with indirect measures like those used here.

Possible Future Applications of the Paradigm

The form of grouping that we have investigated—common color—was held constant throughout the experiments here in order to establish the new paradigm. The success of this series of studies demonstrates the feasibility of our method and suggests that it could subsequently be extended to address many different types of grouping processes, such as grouping by motion, alignment, depth, and modal or amodal completion (e.g., see Driver et al., 2001; Kellman, Yin, & Shipley, 1998; Palmer, 1999; Rock & Broscole, 1964; Treisman, 1982; Wertheimer, 1923; see also Moore et al., 2003). Indeed, some authors have already adapted our new method to examine processing of different forms of grouping under inattention (e.g., see Kimchi & Razpurker-Apfeld, 2004). Several authors have proposed that certain aspects of grouping may not necessarily occur in “early” visual processes, since they appear to be modulated by seemingly sophisticated visual processes, such as subjective-figure construction (e.g., see Palmer, Neff, & Beck, 1996; Palmer & Nelson, 2000). The method developed here could be used to assess whether additional specific forms

of grouping, such as those involved in segmenting subjective figures, can occur without attention (cf. Davis & Driver, 1994; Peterhans & von der Heydt, 1989; von der Heydt & Peterhans, 1989; see also Moore et al., 2003). Finally, because the present method focuses on *changes* in background grouping, it could also be used to assess whether grouping for task-irrelevant background changes can generalize across grouping in different domains (e.g., if a first display had background elements grouped into columns by common color, whereas the subsequent display grouped elements into columns versus rows by a different property, such as common shape, would results similar to those here still arise?).

As well as examining different forms of background grouping and different types of changes to this grouping, the method introduced here could be adapted to examine the impact of different *attentional* conditions on implicit background processing—for example, by increasing the level of perceptual load of the central matrix task. Considerable evidence now suggests that the perceptual load of a primary task can affect the available processing capacity remaining for items outside the focus of attention (e.g., see Lavie, 1995, 2000; Lavie & Tsai, 1994). Load could be further increased within the matrix task used here (e.g., by increasing the number of elements within each matrix), to examine whether there is a point at which implicit processing of unattended background grouping may break down. So far, in the experiments here, central task difficulty was increased in two ways: by shortening the duration of stimuli and by changing target location (thus requiring an intervening saccade). But some processing of background grouping and some sensitivity to whether this changed or not remained evident, at least implicitly. Whether this will still apply at even higher attentional loads remains to be determined.

Conclusion

The present experiments introduced and validated a new indirect method for studying the processing of task-irrelevant background grouping, and of any change in this grouping across visual interruptions or saccades. Our initial results demonstrated the feasibility of this new method and implied that background grouping by common color and changes in this grouping can be extracted under conditions of inattention, including for background elements that are not adjacent to the target item, and even for changes in grouping that arise across a saccadic eye movement. This new paradigm consistently demonstrated that an indirect on-line measure of background grouping can reveal considerably more processing than would be expected based on explicit responses to surprise questions of the type utilized by Mack, Rock, and their colleagues.

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NOTES

1. Error data showed an interaction between target matrix condition (same vs. different) and background configuration [same vs. different; $F(1,19) = 18.14, p < .001$]. Participants again responded significantly more accurately to a *different* matrix pattern when the background also changed (8% correct) than when it did not [13%; $F(1,19) = 21.43, p < .001$]; but accuracy did not differ for same matrices when the background changed (8% correct) or did not (7%). Participants were again no better than chance in judging the nature of grouping (now row vs. column) on surprise retrospective questioning under inattention. Our thanks to Cathleen Moore for motivating this additional study.

2. Our thanks to Steve Most for suggesting this.

3. Our thanks to Dan Simons for suggesting this.

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