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Does training under consistent mapping conditions lead to automatic attention attraction to targets in search tasks?

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Schneider and Shiffrin (1977) proposed that training under consistent stimulus–response mapping (CM) leads to automatic target detection in search tasks. Other theories, such as Treisman and Gelade's (1980) feature integration theory, consider target–distractor discriminability as the main determinant of search performance. The first two experiments pit these two principles against each other. The results show that CM training is neither necessary nor sufficient to achieve optimal search performance. Two other experiments examine whether CM trained targets, presented as distractors in unattended display locations, attract attention away from current targets. The results are again found to vary with target–distractor similarity. Overall, the present study strongly suggests that CM training does not invariably lead to automatic attention attraction in search tasks.

In two seminal articles, Schneider and Shiffrin (1977; Shiffrin & Schneider, 1977)[1] argued that training under consistent mapping conditions leads to automatic attention attraction by the targets in search tasks. In the present study, we test whether this idea is truly grounded in empirical facts.

All experiments involved the single-frame version of the classical visual-memory search task. In such a task, participants have to commit to memory a set of one or more items—the memory (M) set—and to search for the presence of any of these potential targets in a single visual display containing one or more elements—display (D) set—some of which serve as distractors. Consistency of stimulus–response mapping is achieved by selecting the stimuli serving as targets versus distractors from disjoint ensembles. For instance, in Schneider and Shiffrin's (1977) Experiment 2, some participants had to search for one or more digits among a set of consonants. So, whenever a digit was present in the display, it was also a member of the M set and the correct response was "yes." For these participants, digits were consistently mapped onto positive responses over trials, as were consonants for the participants who had to search for consonants among digits. The basic finding, which has been replicated often since Schneider and Shiffrin's study, is that, after extensive training under consistent mapping (CM) conditions, response times (RTs) tend to become independent of the number of items in the M and the D sets.

Schneider and Shiffrin (1977) contrasted performance obtained in CM conditions to that obtained in conditions where stimulus–response mapping was varied. The stimuli used in the varied mapping (VM) conditions were either all digits or all consonants, depending on the participants. The targets and distractors were chosen randomly over trials, so that a given stimulus was associated to a positive response on some trials and to a negative response on others. The performance obtained in VM conditions showed little improvement, in the sense that search times remained largely dependent on both the number of potential targets (i.e., M set size), and the number of characters on the display (i.e., D set size), these two factors interacting with each other. Such interactive size effects were taken as indicative of limited-capacity search.

Shiffrin and Schneider (1977) argued that the flat display search slopes obtained after extensive CM training were attributable to the fact that targets come to automatically attract attention to themselves and away from the distractors. There are several reasons to doubt the validity of S&S's conclusion. First, as noted by Cheng (1985), many of Schneider and Shiffrin's (1977) and Shiffrin & Schneider's (1977) experiments involved a confound of a categorical nature. For instance, in the CM condition of the experiment just described, since the targets and distractors belonged to two distinct and well-known categories, digits and consonants, the results obtained in such conditions can be attributed to this categorical distinction as much as to consistent mapping. S&S were aware of this confound and countered the argument by referring to an earlier study by Briggs and Johnsen (1973), in which all stimuli were letters. Performance was indeed much better in the CM than in the VM conditions of that study. However, the RTs obtained by Briggs and Johnsen in CM conditions exhibited larger size effects than those obtained in Schneider and Shiffrin's Experiment 1. Many methodological differ-

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ences across the two studies, including amount of training, may have contributed to the difference in results.

A more controlled comparison can be found in Cousineau and Larochelle (2004), who duplicated Schneider and Shiffrin's (1977) Experiment 2, using stimuli composed exclusively of letters or digits in addition to stimuli made of letters and digits. With different categories, CM search slopes were almost flat, right from the start of the experiment. Performance obtained in a same-category CM condition never reached an equivalent level of proficiency, even after extensive training. These results confirm that the categorical distinction separating the targets from the distractors does contribute to performance, which suggests that consistency of mapping per se does not suffice to achieve optimal performance in the visual-memory search tasks.

Another reason to doubt that consistency of mapping leads to automatic target detection stems from phenomena and theories of visual search. For instance, according to Treisman and Gelade's (1980) seminal feature integration theory (FIT), automatic detection occurs when the target differs from the distractors by at least one distinguishing feature. To account for target pop-out, Treisman and Gormican (1988) proposed that early visual analysis extracts individual feature maps, which support automatic detection in single-feature or disjunctive search conditions. However, locating a target in conditions that require the joint consideration of two or more features was thought to involve the coordination of separate feature maps, a process assumed to be capacity limited.

Nakayama and Silverman (1986; see also McElree & Carrasco, 1999; McLeod, Driver, & Crisp, 1988; Treisman & Sato, 1990; Wolfe, Cave, & Franzel, 1989) have shown that some feature conjunctions can be detected with little or no effect of number of distractors on the display. However, these conjunctions generally involve attributes such as shape, color, and orientation, which are generally thought to be processed by independent channels in the brain. The same may not apply to conjunctions of features involving the same attribute. Alphanumeric characters, such as those used in visual-memory search tasks, can be conceived as being made of a conjunction of straight and curved lines of different lengths and orientations. Treisman and Gormican (1988) failed to find evidence that conjunctions of such line segments can automatically attract attention.

To avoid the category confound discussed previously, the stimuli used in the present experiments consist only of letters. Moreover, the stimuli used as targets in the CM conditions of the visual-memory search task were selected in such a way that no single feature enabled observers to distinguish the targets from the distractors. Therefore, on the basis of FIT, one should not expect to find automatic detection even after extensive CM training. S&S's automatic attention attraction theory (AAAT), of course, predicts the opposite.

Experiments 1 and 2, reported here, were motivated by these conflicting predictions. Unbeknownst to us at the time, Kyllingsbæk, Schneider, and Bundesen (2001) were doing a study with a purpose similar to ours, using a procedure inspired by Shiffrin and Schneider's (1977) Experiment 4D. To avoid the category confound present in that experiment, the stimuli used in Kyllingsbæk et al.'s study were 18 consonants. The stimuli were drawn in a specifically designed font involving only straight lines of different lengths and orientations. For CM training, the stimuli were divided into two sets, the targets being taken from one set and the distractors from the other. The letters were assigned to the two sets in such a way that, according to Kyllingsbæk et al. (p. 86),

> it seemed impossible to determine whether a stimulus character was a target or a distractor by testing whether the character had a particular simple feature or testing whether the character had at least one out of a particular set of simple features (i.e., testing for a disjunction of simple features).

After extensive CM training, participants were tested under a VM condition. The potential targets forming the M set on a given trial were letters taken among those that had previously served as distractors. When a target was present on the following display, it always occupied one or the other of two positions on the display, the other two locations being known by the participant to be irrelevant. The distractors were also generally taken from the set of stimuli having served as distractors during training, thus the VM condition. However, on some trials, a stimulus having previously served as target during training (a former target) occupied one of the two unattended positions.

According to Kyllingsbæk et al. (2001), if former targets attract attention when they serve as distractor, more false alarms will be made on negative trials and fewer hits will occur on positive trials, all of which will result in smaller d' than when no former target is on display. This is precisely what Kyllingsbæk et al. found; they concluded that the CM trained targets distracted attention from the other stimuli on the display. Since the composition of the stimulus sets was such that the task could not be done by a simple feature search, according to Kyllingsbæk et al., they proposed that "attention was attracted by shapes as complex as individual alphanumeric characters" (p. 93). Experiments 3 and 4 of the present study were designed to test the generality of Kyllingsbæk et al.'s results and the validity of their conclusion.

Although we have focused so far on S&S's AAAT, it is worth mentioning that AAAT is not the only theory of automatization that rests on consistency of mapping. Logan (1988, 1992) proposed that learning occurs by storing instances of the associations involved in a task. Practice is thought to increase the number of stored associations, and automatization is assumed to result from an increased reliance on the retrieval of such traces. Although Logan's theory was not developed in the context of search tasks, it would clearly require some consistency of mapping to account for automatization of performance. In the absence of such consistency (i.e., when the same stimuli serve equally often as target and as distractor over trials), the stored stimulus–response associations become totally uninformative, so that performance on a given trial must rely on some form of algorithmic processing, which could be the type of serial, self-terminating item comparison process originally proposed by S&S.

Analogously, FIT in its original and revised version is not the only theory to rest on a similarity principle. Duncan and Humphreys (1989, 1992; Humphreys, Quinlan, & Riddoch, 1989), for instance, argued that search efficiency does not depend only on the dissimilarity of the target and distractors, as originally proposed by Treisman and Gelade (1980), but also on the similarity among distractors and the similarity among targets.

Similarity- and mapping-based theories lay claim on the same empirical finding—namely, that under certain circumstances, targets will be detected without any attentional resources. Evidence for each class of theory comes from distinct but not altogether different experimental paradigms—namely, visual search and visual-memory search. In some experiments, the main factor manipulated to reveal automatic detection (the number of items in the display) and the measure taken (RT) are identical. The problem that is seldom raised is that similarity- and mapping-based theories seem to make conflicting predictions. As previously discussed, mapping-based theories predict that automatic target detection can occur even under conjunctive search conditions, which is forbidden by many similarity-based theories. By contrast, similarity-based theories allow automatic target detection to occur under varied mapping conditions, provided that the targets are sufficiently different from the distractors, which is forbidden by mapping-based theories. Experiment 1 pits these two principles against each other in order to examine the relative importance of each in a visual-memory search task.

EXPERIMENT 1

The stimuli used in Experiment 1 were eight lowercase letters: *b*, *d*, *h*, *n*, *p*, *q*, *u*, and *y*. A specifically designed font (see Figure 1) was used so that these letters could be roughly described as being made of an open or closed loop, located next to a long or short vertical line extending either upward or downward. There were two experimental conditions in the experiment. For the CM condition, the stimuli were divided into two subsets: (*b*, *n*, *q*, *y*) versus (*d*, *h*, *p*, *u*). In this way no feature was unique to a subset; that is, both subsets contained some letters with open and closed loops, long and short vertical lines extending upward and downward. Note that the curve at the bottom of the *y* had to be deleted to ensure that no stimulus had unique, distinguishing features. The stimuli serving as potential targets on a given trial were selected from one subset for half the participants and from the other subset for the other participants. The remaining subset provided the distractors. If consistent mapping is sufficient for the automatization of search, as proposed by AAAT, this condition should eventually lead to automatic target detection, despite the great similarity of the targets and distractors.

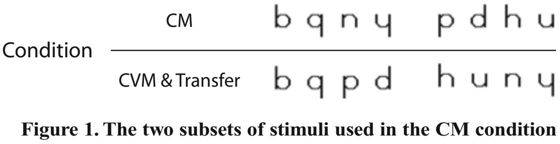

Figure 1. The two subsets of stimuli used in the CM condition and in the CVM and transfer conditions of Experiment 1. Stimuli are shown using the font used in the experiment.

The same stimuli served in the other condition and were also assigned to two different subsets. However, the assignment was such that the two subsets (*b*, *d*, *p*, *q*) and (*h*, *n*, *u*, *y*) could easily be distinguished on the basis of the loop, which was open for one subset and closed for the other.[2] In this condition, the two subsets of stimuli switched roles over trials. If, on a given trial, the targets were taken from one set, the distractors were picked from the other, and vice versa; over trials, therefore, every stimulus served equally often as target and distractor. In other words, every stimulus was associated equally often with the target-present and the target-absent decisions, so that stimulus–response mapping was inconsistent. Following Shiffrin and Schneider (1977), we will call such a condition *categorical varied mapping* (CVM),[3] to distinguish it from *varied mapping* (VM) conditions, in which the targets and distractors are randomly drawn over the ensemble of stimuli.

Since FIT and other similarity-based theories make no provision for mapping, target detection should be easy in the CVM condition, even though the target and/or distractors change from trial to trial. Quite surprisingly, such variations in the targets and distractors rarely occur in the visual search experiments upon which most similarity-based theories rest. In the vast majority of such studies, starting with that of Treisman and Gelade (1980), the target and/or distractors remain the same throughout entire blocks of trials. This constitutes a form of consistency in the mapping of stimuli and responses. However, it has been shown that target pop-out still occurs in feature singleton search, even when participants have no foreknowledge of the target (see, e.g., Wolfe, Butcher, Lee, & Hyle, 2003).

Other methodological differences between visual search and visual-memory search experiments prevent one from assuming that the results obtained in the former will automatically occur in the latter. For instance, in visual-memory search, the number of stimuli presented on the display rarely exceeds eight items and is usually much smaller. The stimuli, target, and/or distractors are all presented within a visual angle of about 2º. In visual search experiments, the number of stimuli on display often exceeds 7±2 items and are distributed over a larger portion of the visual field. If the tokens on display are more numerous than in a visual-memory search experiment, the number of different item types is usually smaller: The same few distractors are repeatedly presented over the field. Such homogeneity allows the formation of groups of distractors, which can be ignored altogether, thereby facilitating target pop-out (Wolfe et al., 1989). One may not obtain similar results when no distractor is repeated, even if the target differs from all distractors by a single feature.

Method

Participants. Eight female undergraduate students at the Université de Montréal participated in the experiment. All were right-handed and had normal or corrected-to-normal vision. The participants were divided into two groups. One group, the CVM-

CM group, trained for 5 sessions under the CVM condition before training under the CM condition for 5 other sessions. The other group, the CM-CVM one, also trained for 10 sessions, but the order of conditions was reversed. After training, participants in the CM-CVM group also did 2 transfer sessions. Swapping of the subsets stopped at transfer, the stimuli in one subset serving as targets for half of the participants and as distractors for the other half. The goal of this transfer condition was to determine the level of performance achieved when consistency of mapping and ease of discrimination act together instead of against each other.

Participants were not explicitly informed of the set composition of the stimuli in the various training and transfer conditions. However, when starting in a new condition, participants were warned that something could be different, although the search task remained the same. Sessions were run on separate days and lasted about 50 min each. In addition to receiving Can$10 per session, participants could earn a bonus of Can$2.50 per session if their average RT for the session was shorter than that of a paired participant in the same group. (Error rate also had to be smaller than 5% for the participant to be entitled to the bonus.) This competition was designed to maintain the motivation of the participants, who were not informed of the results of the competition until the end of the experiment, to avoid possible discouragement.

Procedure. A personal computer equipped with a VGA screen was used to run the experiment, which was programmed using the MEL software (Schneider, 1989). All characters used in the experiment were displayed as white figures on a black background. Every trial began with the presentation of an asterisk in the center of the screen. After 500 msec, one, two, or four letters were presented for 1 sec in the center of the same line as the preceding asterisk. Order of the letters on the line was random. These letters formed the M set, the participants' task being to search for any one of the M set items in the subsequent test display. After the M set, and before the test display, the asterisk reappeared in the center of the screen for 500 msec. The subsequent test display also consisted of one, two, or four letters. The letters in the D set were presented on the corners of an imaginary square in the center of the screen. Assignment of the letters to the various corners was random and asterisks filled the unoccupied positions when fewer than four letters were present. From a distance of 55 cm, each letter covered about 0.5º of visual angle horizontally and either 0.5º or 0.7º vertically, the entire display covering 1.9º in both directions.

At most, one M set item could be present in the D set on positive trials. Participants indicated target presence by pressing the "1" key located on the numeric keypad of the computer keyboard, using the right index finger. They indicated target absence by pressing the "2" key, using the right middle finger. The display remained visible until the participant responded, or until 3 sec had elapsed. On correct trials, the words CORRECT RESPONSE were displayed, along with the RT. On incorrect trials, or after 3 sec, a brief tone was heard and the words WRONG RESPONSE were displayed. This feedback stayed on for 1.5 sec before the next trial started (with the presentation of the asterisk in the center of the screen).

Each session was composed of eight blocks of 72 trials each, for a total of 576 trials per session. Half of the trials within each block were positive (target present) and half were negative (target absent). Each of the nine combinations of M set size (1, 2, or 4) by D set size (1, 2, or 4) was equally represented for each response R (positive and negative) within each block. Moreover, each target was used equally often on positive trials within each M × D combination. Since there were four possible targets in the CM condition, each was used once per M × D combination within each block. Since there were twice as many possible targets in the CVM condition, it took two successive blocks for every target to appear once on positive trials in every M × D combination. Order of trials within blocks was random. At the end of each block, participants were informed of their mean correct RT and of their error rate. A message reminded the participants that their error rate was too high when it exceeded 5%. Another message encouraged the participants who so desired to take a short rest before proceeding to the next block of trials.

Results

We will first report the results obtained on the last training session under the CM and CVM conditions before turning to the results obtained at transfer. Since the experiment involved a within-subjects design, it must be remembered that some participants started training under CM conditions before switching to CVM conditions, whereas others did the opposite. Consequently, the expression "last training session" must be interpreted relative to a given condition rather than in absolute terms.

Last training session. Error rates were 1.8% in the CVM condition and 2.3% in the CM condition, and were 2.7% for positive and 1.4% for negative trials. Error rates tended to increase with M and D set size. Correlations computed between the error rates and the mean RTs obtained in each of the 18 memory × display × response conditions failed to reveal reliable evidence of speed–accuracy trade-off for any of the participants under either CM or CVM conditions.

An ANOVA was performed on the RT. All RT analyses reported herein were restricted to correct responses only. Trials with RTs smaller than 300 msec or longer than 3,000 msec were also excluded from such analyses. No RT exceeded these limits on the last training session. Apart from the groups (CM-CVM or CVM-CM) and conditions (CM vs. CVM), the factors involved were M set size, D set size, and response (R) type. The ANOVA revealed no significant effect or interaction (all ps $> .13$) involving the group factor, which suggests that potential effects of the order of CM versus CVM training had vanished by the last training session under a given mapping condition. Figure 2 shows the mean RTs obtained on the last training session averaged over both groups of participants. To ease visual comparison, the scale of Figure 2 was chosen to be the same as that of all further figures illustrating RT results in the present study.

As illustrated in Figure 2, CM performance shows M set size to interact with D set size on both positive [$F(4,24) = 29.66$, $MS_e = 1{,}107$, $p < .001$, $\eta_p^2 = .832$] and negative trials [$F(4,24) = 57.29$, $MS_e = 1{,}658$, $p < .001$, $\eta_p^2 = .905$]. The fact that the M × D interaction was more pronounced on negative trials resulted in a significant M × D × R interaction [$F(4,24) = 6.64$, $MS_e = 1{,}285$, $p < .001$, $\eta_p^2 = .525$]. This pattern of results corresponds to what S&S would have attributed to a limited-capacity, serial self-terminating search process. It contrasts sharply with the results obtained in the CVM condition (shown at the bottom of Figure 2), the condition × M × D × R interaction being significant [$F(4,24) = 5.38$, $MS_e = 847$, $p < .01$, $\eta_p^2 = .473$]. CVM performance failed to exhibit reliable M × D [$F(4,24) = 1.19$, $MS_e = 186$, $p = .34$, $\eta_p^2 = .166$] and M × D × R interactions [$F(4,24) = 1.95$, $MS_e = 235$, $p > .13$, $\eta_p^2 = .245$]. The D set size effect was more pronounced on positive than on negative trials, resulting in a significant D × R interaction [$F(2,12) = 6.07$, $MS_e = 506$, $p < .02$, $\eta_p^2 = .503$], and so was the M set size

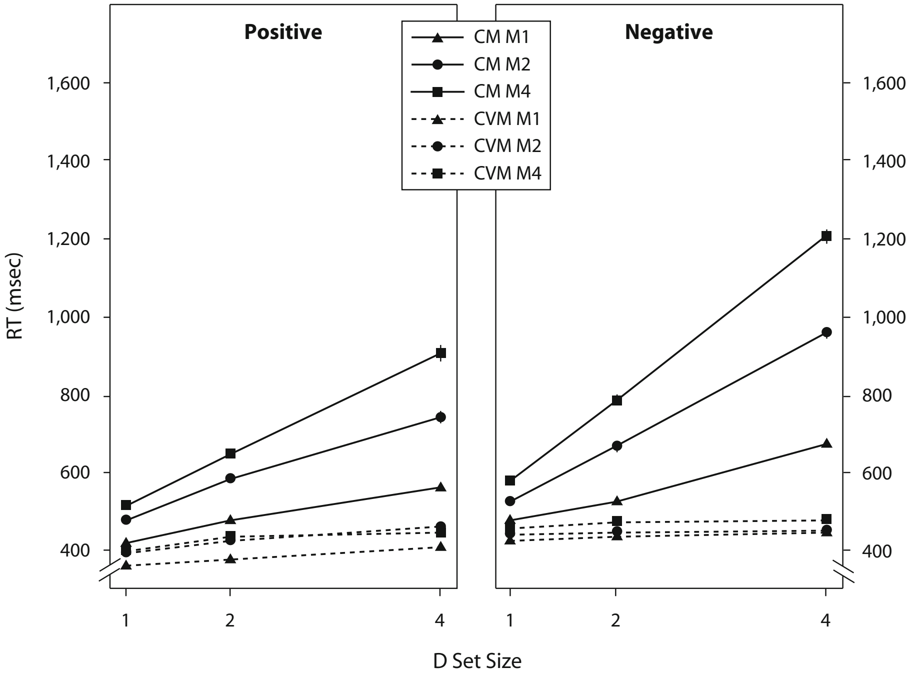

Figure 2. Mean response times (RTs) and standard errors obtained on the last training session of Experiment 1. Results are presented separately for each response type (positive or negative trials) as a function of mapping condition (CM or CVM), D set size (1, 2, or 4), and M set size (1, 2, or 4).

effect (M × R) [$F(2,12) = 17.35$, $MS_e = 184$, $p < .001$, $\eta_p^2 = .743$]. Linear regression analyses showed the display and memory search rates obtained on positive trials to be significantly different from zero [display, 16 msec/item, $r(70) = .38$, $p = .001$; memory, 12 msec/item, $r(70) = .28$, $p = .017$], but not those obtained on negative trials [display, 6 msec/item, $r(70) = .13$, $p = .26$; memory, 10 msec/item, $r(70) = .21$, $p = .074$].

Transfer session. An ANOVA was performed to compare the RTs obtained by group CM-CVM on the last CVM training session with those obtained by the same participants on the last half of the final CM transfer session. Recall that the open and closed-loop characters stopped switching roles as targets and distractors during CM transfer. Half of the participants systematically searched for open-loop targets among closed-loop distractors, and vice versa for the others. Since there were half as many possible targets in transfer CM as there were in prior CVM training, one half-CM transfer session provided as much practice per target as one full CVM training session did. We chose to focus on the last half of the final transfer session to get a view of the best CM performance available. One trial was excluded from analyses because of an RT greater than 3,000 msec.

The ANOVA showed the average RTs to be a nonsignificant 7 msec shorter, on average, at the end of CM transfer than at the end of CVM training. The mapping effect [$F(1,3) = 0.02$, $MS_e = 86{,}632$, $p > .50$], and all the interactions involving mapping, failed to reach statistical significance. Slope analyses showed display search to be nonsignificantly slower in CM transfer than at the end of CVM training on both positive trials [CM, 17 msec/item; CVM, 13 msec/item; $t(3) = -0.93$, $p = .42$] and negative trials [CM, 4 msec/item; CVM, 3 msec/item; $t(3) = -1.16$, $p = .33$]. Memory search rates were almost identical in CM transfer and at the end of CVM training on both positive trials [CM, 12 msec/item; CVM, 11 msec/item; $t(3) = -0.44$, $p = .69$] and negative trials [CM, 5 msec/item; CVM, 6 msec/item; $t(3) = 0.41$, $p = .70$]. In short, consistency of mapping did not lead to any improvement in performance beyond that obtained with highly discriminable sets of stimuli in the CVM condition.

Discussion

The results of Experiment 1 show that target–distractor dissimilarity is much more critical to the automatization of performance in visual-memory search than is consistency of stimulus–response mapping. Indeed, search became very efficient when targets were highly dissimilar to distractors, despite lack of consistency in mapping. Should one conclude that target detection was automatic in this CVM condition?

On the positive side, the slopes obtained on negative trials after extensive CVM training were not significantly different from zero and within the 10 msec/item range that some (e.g., Chun & Wolfe, 2001) would associate with automaticity. The larger display search rates obtained on positive trials could be attributable to a postdetection verification stage. Upon detection of a target-defining feature on display, participants may verify that other display locations do not contain the same feature because, if so, the feature would belong to a distractor instead of to a target. Note that participants using such a strategy on a given trial would not even have to remember whether they were searching for an open- or a closed-loop target; they would simply have to search for a singleton on the display. Larger memory search rates obtained on positive rather than on negative trials could be given a similar explanation. Upon detecting a single open (or closed) loop item in the display, participants might be tempted to verify that this item was indeed part of the M set. Such verification would not occur on negative trials, since no target is present on the display. Although no memory check is necessary on positive trials, participants may not always refrain from doing one.

On the negative side, some authors (e.g., Joseph, Chun, & Nakayama, 1997) have argued that slopes of 0 msec/item do not even suffice to conclude that detection is automatic. In order to conclude that search uses absolutely no attentional resource, they would require performance to remain as efficient in a dual-task context. By contrast, Czerwinski, Lightfoot, and Shiffrin (1992, Experiment 1C) simply required that CM performance remain more proficient than VM performance in a dual-task situation, in order to conclude that processing in the CM condition was automatic.

Determining whether performance relies on automatic versus controlled processing clearly depends on the criteria used. Shiffrin and Dumais (1981) discussed over a dozen properties of automatisms, which is clearly more than any one experiment can test for. What the present experiment suggests is that search in the CVM condition was as efficient as it can get in a visual-memory search task involving only alphabetic characters. Consistency of mapping was not necessary to achieve this optimal level of performance (whether or not it is qualified as automatic), and it did not lead to significant further improvement beyond that obtained at the end of CVM training.

With highly similar targets and distractors, the RTs obtained after five training sessions under CM conditions still exhibited large interacting memory and display load effects indicative of limited capacity search. It is therefore tempting to conclude that consistency of mapping is not sufficient to achieve optimal search performance. However, such a conclusion may be premature. Mean RTs were 774 msec on the first CM training session and 568 msec on the fifth. It is possible that performance in the high target–distractor similarity CM condition would continue to improve with further practice, perhaps ultimately reaching the level of efficiency observed in the low target–distractor similarity CVM condition. The goal of Experiment 2 was to test this issue.

EXPERIMENT 2

Experiment 2 duplicates the high-similarity CM condition of Experiment 1. The amount of training was increased to 5,760 trials for one group of participants (compared with 2,880 trials in the CM condition of Experiment 1), and to 11,520 trials for another. Another difference from Experiment 1 concerns the transfer sessions: After extensive CM training, participants were transferred to a CVM condition, in which both sets of stimuli switched roles as targets and distractors. The purpose of this transfer condition was to examine the deterioration in performance caused by the loss of consistency of mapping.

Method

Eight right-handed undergraduate students participated in Experiment 2, 4 in each group. There were 2 males and 2 females in each group. As in Experiment 1, participants received Can$10, plus a possible Can$2.50 bonus per session. There were 10 training sessions for one group (Group 1) and 20 training sessions for the other group (Group 2), followed by a transfer session for both groups. The stimuli and stimulus sets were exactly the same as those used in the CM condition of Experiment 1 (see Figure 1). During training, one set served as targets for half of the participants of each group, the other set serving as distractors, and vice versa for the remaining participants. During transfer, both sets switched role as targets and distractors randomly over trials, for all participants. The presentation conditions and visual angles subtended by the stimuli were the same as in Experiment 1. The experiment was controlled by MEL professional software version 2.1, installed on personal computers equipped with 600-MHz processors. Standard SVGA 15-in. screens were used to display the stimuli.

Results

Last training session. Mean error rates were 3.11% for Group 1 on the 10th session and 3.78% for Group 2 on the 20th session. Analyses similar to those performed in Experiment 1 gave no indication of speed–accuracy trade-off. Overall, 1.3% of the RTs were excluded from the RT analyses, because they were outside the 300- to 3,000-msec range.

Average RT was smaller after 20 training sessions (507 msec) than after 10 sessions (567 msec), but not reliably so [$F(1,6) = 4.28$, $MS_e = 20{,}812$, $p = .084$, $\eta_p^2 = .416$]. Comparison of Figure 3 with Figure 2 shows that CM performance continued to improve after 5 training sessions. The M × D × R interaction, still present on the 5th session in Experiment 1, failed to be significant in Experiment 2 [$F(4,24) = 1.99$, $MS_e = 610.95$, $p = .129$, $\eta_p^2 = .249$] on both the 10th and the 20th sessions [group (G) × M × D × R: $F(4,24) = 2.04$, $p = .120$, $\eta_p^2 = .254$]. However, a significant M × D interaction was still present in the performance of Group 1 on the 10th session [$F(4,24) = 29.64$, $MS_e = 473$; $p < .001$, $\eta_p^2 = .832$], but not in that of Group 2 on the 20th [$F(4,24) = 0.67$, $p = .62$, $\eta_p^2 = .100$], the difference across groups being reliable [G × M × D: $F(4,24) = 11.73$, $MS_e = 473$, $p < .001$, $\eta_p^2 = .662$]. For Group 2, D set size failed to interact with R type [$F(2,12) = 2.11$, $MS_e = 709$, $p = .164$, $\eta_p^2 = .260$] and so did M set size [$F(2,12) = 0.15$, $MS_e = 407$, $p = .863$, $\eta_p^2 = .024$].

On the 20th session of CM training with highly similar targets and distractors, the mean D slope was 31 msec/item on positive trials and 39 msec/item on negative trials. Recall that corresponding slopes were 16 msec/item and 6 msec/item, respectively, on the 5th session of CVM training with highly dissimilar targets and distractors in Experiment 1. The difference across conditions was significant for both positive trials [$t(10) = 3.71$, $p = .004$, $\eta_p^2 = .579$] and negative trials [$t(10) = 7.54$, $p < .001$, $\eta_p^2 = .850$]. On the 20th CM training session, the mean M slope was 22 msec/

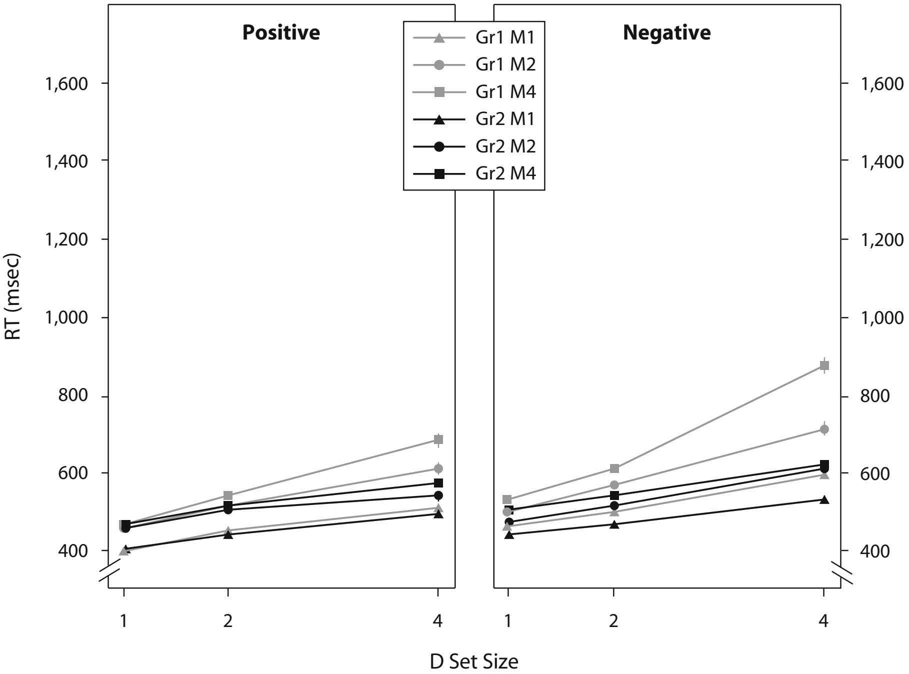

Figure 3. Mean response times (RTs) and standard errors obtained on the last training session of Experiment 2. Results are presented separately for each response type (positive or negative trials) as a function of group (1 or 2), D set size (1, 2, or 4), and M set size (1, 2, or 4).

item on positive trials and 23 msec/item on negative trials, compared with 12 msec/item [$t(10) = 2.28$, $p = .025$, $\eta^2_p = .342$] and 10 msec/item [$t(10) = 2.27$, $p = .046$, $\eta^2_p = .340$], respectively, on the 5th CVM training session of Experiment 1.

Longitudinal analyses. Would CM performance improve further with additional training? Being interested in the improvements of the search and comparison processes rather than in intercept processes, we cannot simply analyze the evolution of RTs over training, because RTs incorporate a component due to intercept processes. On the other hand, one cannot simply compute separate visual and memory search slopes for every training session, because memory and display size effects sometimes interact. Our solution was to compute a measure of search times by subtracting the mean correct RTs obtained under the smallest load condition (i.e., with M and D sets of size 1, a condition labeled M1D1) from those obtained under the largest load condition (i.e., M4D4). This calculation can be done irrespective of the additive or nonadditive nature of the M and D set size effects, and it leaves out the component of the RTs due to intercept processes in M1D1 RTs. The results are shown in Figure 4. To verify that search times had stabilized, we performed a session × response ANOVA on the search times of Group 2 on the last five training sessions—that is, on Sessions 16 to 20. This ANOVA revealed that search times were reliably shorter on positive than on negative trials [$F(1,3) = 101.61$, $MS_e = 105$, $p < .01$]. However, search times did not vary significantly over the last five training sessions [S, $F(4,12) = 0.48$, $MS_e = 1{,}220$, $p = .751$; S × R, $F(4,12) = 0.69$, $MS_e = 729$, $p = .616$]. So it appears that if performance had not reached asymptote yet, it had at least reached a plateau.[4]

Transfer session. As mentioned, transfer consisted of a CVM condition in which former targets and distractors remained in different sets but switched role from one trial to another. Error rates were higher at transfer: 4.7% for Group 1 and 7.5% for Group 2. There was no speed–accuracy tradeoff. In total, 0.48% of the data was removed, because RTs were either below 300 msec or over 3,000 msec. Correct RTs at Sessions 11 and 21 (for Groups 1 and 2, respectively) are plotted in Figure 5. As can be seen, performance was highly disrupted by the change in mapping, exhibiting the pattern of M × D × R [$F(4,24) = 6.06$, $MS_e = 3{,}510$, $p < .01$, $\eta^2_p = .502$] characteristic of limited-capacity processing. Performance of Group 2 appears to have been slightly less affected than that of Group 1. However, only the G × D interaction approached significance [$F(2,12) = 2.92$, $MS_e = 13{,}101$, $p = .09$, $\eta^2_p = .329$]. All other effects and interactions involving the group factor had p values larger than .26. In sum, although Group 2 had twice as much practice, its performance did not differ much from that of Group 1 at transfer.

Where did the disruption of performance come from? On half the trials, the stimuli serving as targets were exactly the same as they were during prior CM training, the same being true of the stimuli serving as distractors. According to AAAT, performance should have remained fairly unhindered in this case: If the former targets were attracting at-

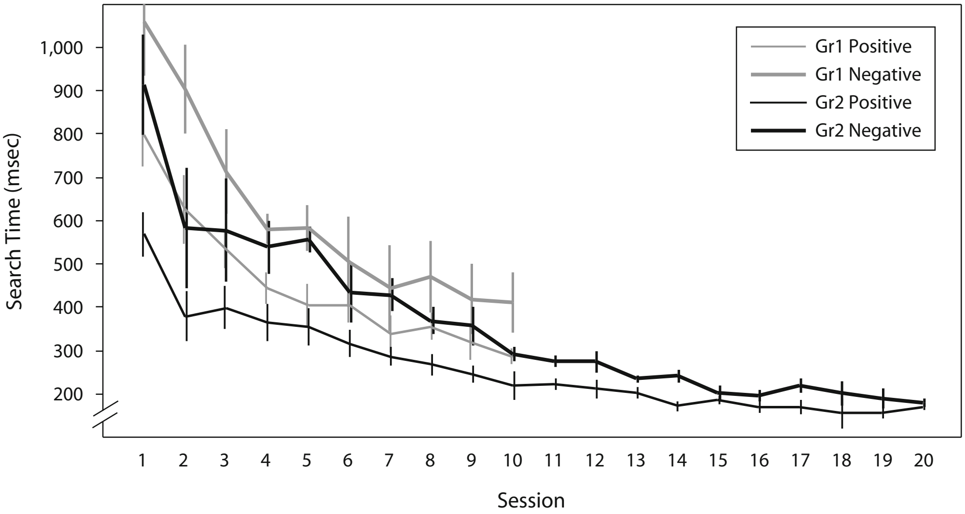

Figure 4. Estimated search times at each session of Experiment 2 as a function of group (1 or 2) and response type (positive or negative trials).

tention on Session 20, they should have continued to do so at least at the beginning of transfer. On the other half of trials, the old distractors now served as targets and the old targets as distractors. Such a reversal was found by Dumais (1979) to be the condition most detrimental to performance: AAAT predicts that the old targets, which now serve as distractors, should attract attention to themselves and away from the new targets. Consequently, performance on these trials should be even worse than at the start of training, since mapping was consistent then and since there was no prior training to take attention away from the targets.

Figure 6 displays mean RTs of Group 2 for old and new targets on Session 21, as well as the mean RTs obtained on Session 1. As can be seen, performance was characterized

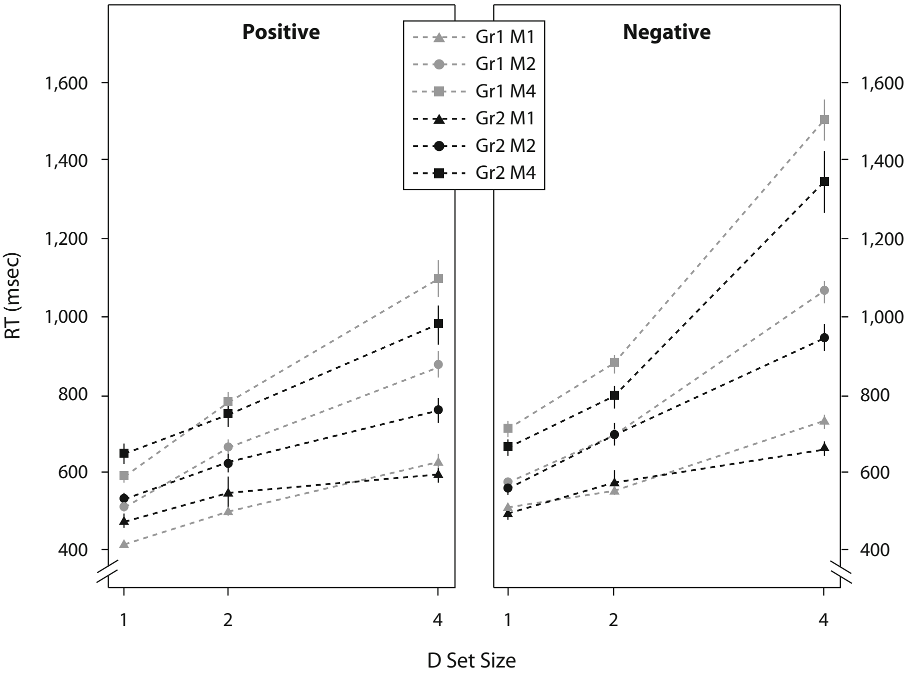

Figure 5. Mean response times (RTs) and standard errors obtained at transfer in Experiment 2. Results are presented separately for each response type (positive or negative trials) as a function of group (1 or 2), D set size (1, 2, or 4), and M set size (1, 2, or 4).

by an M × D × R interaction [$F(4,12) = 4.45$, $MS_e = 7{,}869$, $p < .03$, $\eta_p^2 = .597$], even in the old target condition. The magnitude of the interaction did not differ across target conditions [$F(8,24) = 0.21$, $MS_e = 8{,}376$, $p = .99$, $\eta_p^2 = .066$]. The M × D interaction [$F(4,12) = 14.2$, $MS_e = 17{,}268$, $p < .001$, $\eta_p^2 = .825$] also failed to differ across target conditions [$F(8,24) = 1.61$, $MS_e = 6{,}097$, $p = .18$, $\eta_p^2 = .349$]. However, the effects of D set size did vary over target conditions [$F(4,12) = 4.65$, $MS_e = 17{,}024$, $p < .02$, $\eta_p^2 = .608$], the old targets being searched more rapidly than the new targets and the first session targets.

Discussion

Compared with that observed in the CM condition of Experiment 1, performance improved greatly after more extended training in Experiment 2. The M × D × R interaction, which was still present on the 5th CM training session of Experiment 1, was absent from performance obtained on the 10th training session of Experiment 2. Performance obtained on the 20th session of CM training did not even exhibit an M × D interaction. Had target detection become automatic? The improvement in performance was certainly dramatic enough to satisfy Shiffrin and Dumais's (1981) "improvement with practice" criterion. However, the 20- to 30-msec/item search rates obtained in Experiment 2 are far from meeting the requirement of unlimited capacity, parallel processing. Of course, one could still argue that these slopes originated at a later, controlled stage of processing, such as a verification stage for instance, and still maintain that initial target detection was itself automatic. Although it would be nice to be able to settle the issue to everyone's satisfaction, in a sense it is not critical to our point. What matters, and what Experiment 2 clearly shows, is that extensive CM training did not lead to optimal performance in the visual-memory search task. After more than 10,000 training trials, search rates were still at least twice as large as those obtained after eight times less practice per target under CVM training in Experiment 1. Would performance improve much further with additional CM training? This is unlikely, since our longitudinal analyses showed performance to have already stabilized after 7,500 training trials; this already exceeds the amount of CM training found in many earlier studies devoted to visual-memory search.

The results obtained at transfer further show the effects of CM training to be short-lived (not what one would expect from an automatism, albeit acquired). On the very first CVM transfer session, performance was characterized by a reliable M × D × R interaction, even when the targets and distractors were the same as during prior CM training. Display search was nonetheless more efficient when it involved previously trained targets than when the task required detection of a target, having served as distractor during prior CM training, among distractors consisting of previously trained targets. However, in the latter case, performance was not any worse than on the very first session of CM training. This result suggests that the use of trained targets as distractors did

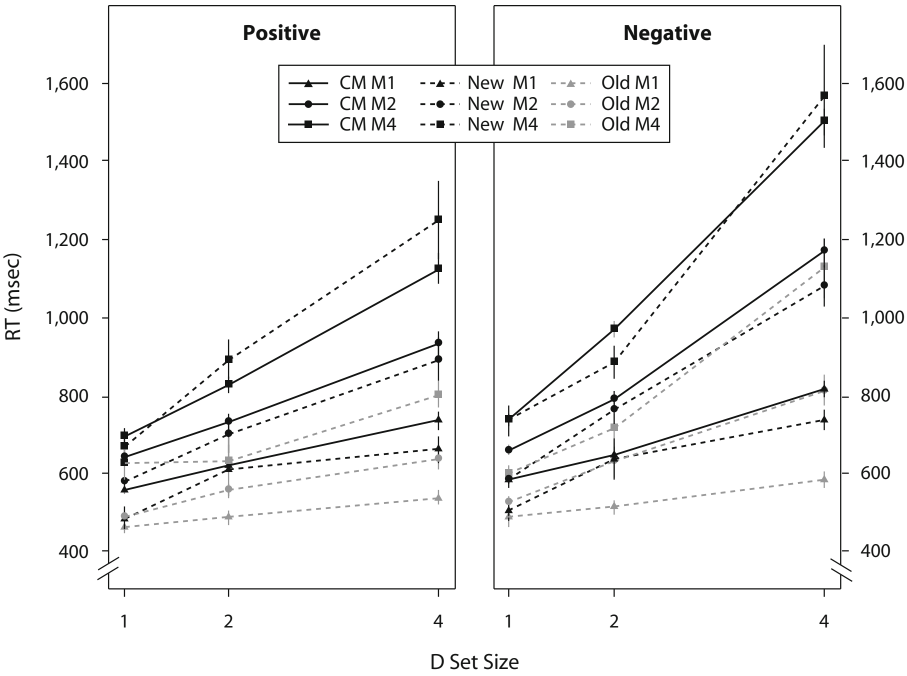

Figure 6. Mean response times (RTs) and standard errors of Group 2 obtained on the first training session and with old and new targets at transfer in Experiment 2. Results are presented separately for each response type (positive or negative trials) as a function of target type (target at first training session, old target at transfer session, or new target at transfer session), D set size (1, 2, or 4), and M set size (1, 2, or 4).

not hinder search for the current target. When considered together, the results of the training and transfer sessions of Experiment 2 do not lend much support to the idea that CM training leads to automatic attention attraction toward targets and away from the distractors, when the targets and distractors are highly similar.

Kyllingsbæk et al. (2001) drew the exact opposite conclusion from their study. Both conclusions rest on results that are clearly at odds with each other: How can a trained target, presented for 43 msec among three distractors (as was the case in Kyllingsbæk et al.'s, 2001, Experiment 2) automatically attract attention, considering that the best display search rates we obtained after extensive CM training averaged about 30 msec/item? Such a search rate would permit the analysis of fewer than two display items during 43 msec, not four. Of course, there are large methodological differences between Kyllingsbæk et al.'s experiments and ours. Their experiments involved short display durations, with postexposure masks, and accuracy was the measure of performance. By contrast, we used long unmasked-display durations and measured RTs. To eliminate the possibility that the theoretical difference between our conclusion and Kyllingsbæk et al.'s might be due only to methodological differences, we decided to adopt Kyllingsbæk et al.'s stimuli and procedure in an attempt to first determine whether their findings held up, then, the case being, to explain the origin of their results.

EXPERIMENT 3

Experiment 3 was as precise a duplication of Kyllingsbæk et al.'s (2001) Experiment 2 as we could achieve.

Method

Participants. Eight students from the Université de Montréal participated in Experiment 3. They averaged 24 years of age. All participants had normal or corrected-to-normal vision, and all were right-handed. Each received Can$100 as compensation for participation.

Stimuli. Figure 7A shows our reproduction of the 18 consonants used in Kyllingsbæk et al.'s (2001) experiments. Each letter was 1.1 cm wide and 1.5 cm high, subtending 0.5º and 0.7º of visual angle, respectively, at the viewing distance of 120 cm. The patterned mask used in the experiment resulted from the superposition of all 18 letters and is shown at the far right of Figure 7A. Following Kyllingsbæk et al., the letters were presented as white outlines on a black background, as was the mask.

Procedure. The procedure followed in the present experiment was identical to that of Kyllingsbæk et al.'s (2001) Experiment 2, with the following exception: At the beginning of CM training, the search display was presented for 72 msec before the masks appeared. However, as soon as a participant's performance reached 85% correct for a whole session, display duration was lowered to 43 msec, and remained as such for the rest of the eight training sessions. Display duration was 43 msec for all participants during the two VM transfer sessions. It may be worth adding, since this is not explicitly stated by Kyllingsbæk et al. that participants also received feedback about accuracy of responding on transfer trials. The feedback given at transfer was identical to that used during training.

Our experiment was run on an HP Compaq computer equipped with an Intel Pentium IV processor and an HP model 7550 17-in. screen. Stimulus presentation and data collection were done using an E-Prime (Schneider, Eschman, & Zuccolotto, 2002a, 2002b) program.

Figure 7. (A) Replica of Kyllingsbæk et al.'s (2001) stimuli used in Experiment 3. (B) Stimuli used in Experiment 4. Within each half, the top nine letters formed one set and the bottom nine letters another set. The patterns next to Z and X were obtained by superposing the nine letters in the corresponding set. The stimuli on the far right were the masks used in each experiment. They were formed by the superposition of the corresponding 18 letters.

Results

Following Kyllingsbæk et al. (2001), we computed a separate d' and log β for each participant on every training session. Over all participants, mean d' increased from 1.69 to 2.85 from the 1st to the 8th session, indicating increasing target discriminability. The mean log β remained fairly constant: 0.15 on the 1st session versus 0.19 on the 8th. We computed two distinct d's and log βs for each participant at transfer, one for trials with a former target present (FTP) on the display and one for trials with no former target on the display (former target absent or FTA). Figure 8A shows the individual d's obtained in these two conditions along with those obtained on the last training session; Figure 8B shows the corresponding log βs. Mean d' was significantly smaller on FTP trials (2.43) than on FTA trials (2.55) [$t(7) = 2.55, p < .05$], which suggests that detection of new targets was impaired by the presence of former targets. There was no significant difference in log β across trial types [$t(7) = 0.04, p = .968$].

To examine the relationship between the efficiency of target detection at the end of training and the strength of target attention attraction at transfer, we computed a correlation between the d's obtained on the last training session and the difference in those d's obtained in the FTP and FTA conditions at transfer. The correlation was not quite significant [$r(6) = -.65, p = .083$]. Note that the correlation obtained is largely due to Participant 2, whose performance exhibited the second smallest d' at the end of training and a reversed FTP minus FTA difference at transfer.

Following Kyllingsbæk et al. (2001), we have reported the results obtained over both transfer sessions. However, we also performed analyses on each one separately. These analyses showed the difference in d' between the FTP and FTA conditions to be significant only on the second transfer session of Experiment 3 [$t(7) = 3.67, p = .008$].[5] The

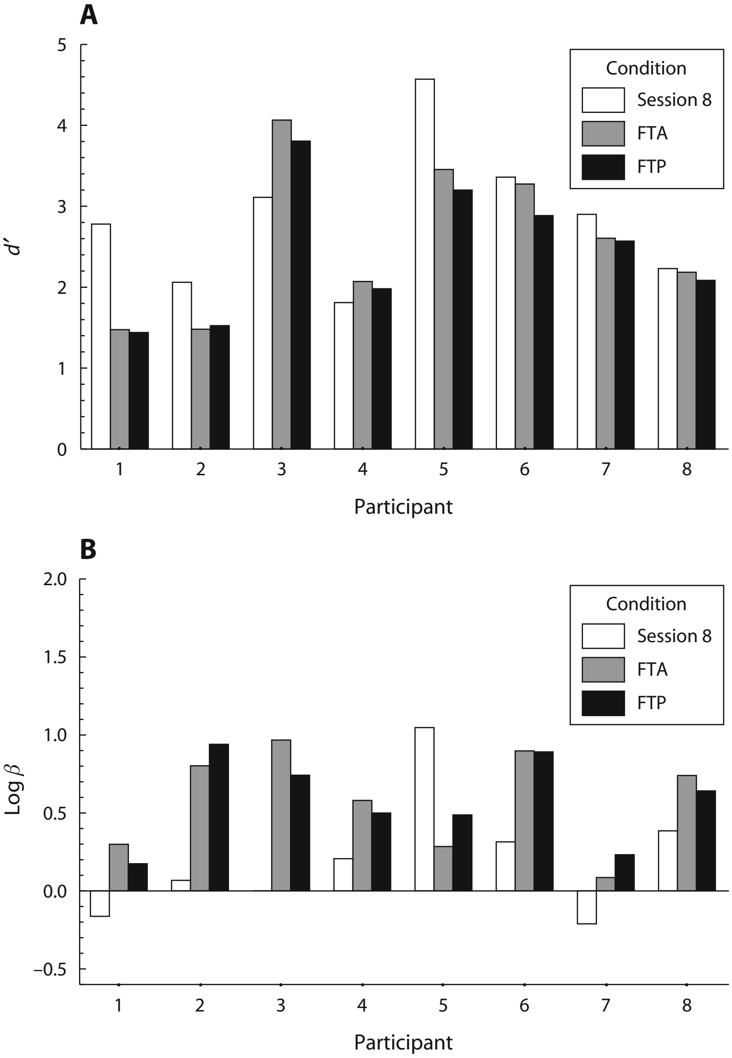

Figure 8. (A) *d′* at transfer for each participant in former target present (FTP) and former target absent (FTA) conditions of the VM transfer sessions, as well as the individual *d′*s obtained on the last CM training session of Experiment 3. (B) The corresponding log *β*s.

correlation between the *d′*s obtained at the end of training and the difference between the FTP and FTA *d′*s at transfer was also closer to significance [$r(6) = -.67, p = .069$] than when computed over both transfer sessions.

Discussion

Kyllingsbæk et al. (2001) gave a perceptual explanation of their findings. Following S&S, they argued that CM training caused trained targets to automatically attract attention. We indeed found some indication that the efficiency of target detection at the end of CM training was related to the amount of attention attraction at transfer. However, further analyses reported here suggest that the difference in *d′* between FTP and FTA trials may not have originated solely at the perceptual level.

A strictly perceptual explanation of the attention attraction phenomenon would probably predict that the effects would be more pronounced immediately after CM training (i.e., on the first transfer session) and would wane with VM practice, because the targets used on VM trials were different from those used during prior CM training. By contrast, a memory-based explanation could perhaps account for the fact that the effect was present only on the second transfer session. Early on, in VM transfer, participants may be very careful not to rely on learned stimulus–response associations to perform the difficult VM search task, because such reliance would invariably lead them astray. However, VM trials may cause associations to be formed between the new targets (former distractors) and the YES response, and also possibly between old targets (new distractors) and the NO response. Although uninformative overall in VM conditions, some of these new traces can lead to the correct response on some trials so that, with more VM training, participants may lose the ability to completely filter out information coming from memory. Moreover, on trials where the M set is lost from short-term memory, the temptation to rely on long-term memory traces, instead of merely guessing, could be strong. In short, with more VM trials, the associations in memory become more muddled so that, on FTP trials, some of the old associations involving former targets and/or former distractors may be retrieved, thereby influencing the decision and/or response selection process. Experiment 4 investigates further the perceptual aspects of the task.

EXPERIMENT 4

Kyllingsbæk et al. (2001) designed their stimuli in such a way that no single feature or disjunction of simple features is allowed to distinguish all the stimuli in one set from all the stimuli in the other set. Although this may be true, some line segments were still uniquely found only among some letters of one set. This is illustrated by the patterns shown next to Z and X in Figure 7A, which were produced by superposing the nine letters in the corresponding set. Had all line segments been present among the stimuli of both sets, these two patterns would be identical. The patterns differ because some characters had unique line segments. A close analysis of Kyllingsbæk et al.'s stimuli reveals that, if line segments do constitute effective features, more than a third of the stimuli could be detected on the basis of a single feature.

Experiment 4 aimed at testing whether distinctive line segments present among Kyllingsbæk et al.'s (2001) stimuli could have contributed to the results obtained in Experiment 3. If so, eliminating these distinctive features would also eliminate, or at least reduce, attention attraction by trained targets. In order to test this possibility, we redesigned some of the characters used in Experiment 3.

Method

Stimuli. The stimuli used in Experiment 4 are shown in Figure 7B. Before these stimuli are described, the reader is invited to experience the ease with which these characters can be identified. In fact, it is difficult to tell that there are differences between these characters and those used in Experiment 3 (illustrated in Figure 7A). However, the masks illustrated at the right of Figure 7 show that the characters used in Experiment 4 were made of a smaller number of distinct line segments than were the characters used in Experiment 3. In the stimuli of Experiment 4, there were also fewer line segments found uniquely among the characters of one set, as illustrated by the similar, though not identical, patterns shown next to Z and X in Figure 7B.

In fact, all but four of the characters used in Experiment 3 remained the same in Experiment 4. Only K, M, Q, and R were modified. K, Q, and R were modified so that the descending oblique line in their bottom right part would coincide perfectly with the descending oblique line in the bottom parts of the X and N. This previously distinctive feature was now shared by three stimuli in one set and two in the other. The K's top right oblique line was also changed to coincide with the top right oblique line in the X and Z. The M was modified so that the two oblique lines in its top part would coincide perfectly with the top part of the X. Considering the feature set available, the distinctive features of the S, V, and T could not be changed without compromising their identity and the ease with which they could be identified, and so they remained "distinct."

Participants. Eight students from the Université de Montréal participated in Experiment 4. They averaged 22 years of age. All had normal or corrected-to-normal vision, and all were right-handed. Each received Can$100 as compensation for participation. They were submitted to the same experimental procedure as were the participants of Experiment 3, and their data were subjected to the same analyses.

Results

On the first training session, d' was at about the same level in Experiment 4 (mean $d' = 1.72$) as it was in Experiment 3 (mean $d' = 1.69$). However, d's increased by only 0.57 units on average over the course of training in Experiment 4, compared with 1.16 units in Experiment 3. As shown in Figure 9A, transfer d's were smaller on FTP trials than on FTA trials for only about half of the participants. There was no significant difference in mean d' for FTP (2.09) and FTA (2.13) trials [$t(7) = 1.21, p = .267$]. This lack of effect cannot be attributed to some sort of bias (see Figure 9B), since log βs did not differ significantly either across trial types [mean log β: FTP, .49; FTA, .55; $t(7) = -1.08, p = .315$]. Separate analyses performed on the two transfer sessions revealed no significant difference in either d' or log β across the FTP and FTA conditions on either session. The correlation between the d's obtained on the last training session and the difference between the FTP and FTA d's was far from significant, whether computed separately for each transfer session or for both sessions (all ps $> .31$).

Discussion

The results obtained with our modified stimuli in Experiment 4 show that CM training did not contribute much to performance. Participants did not become much more efficient at discriminating targets from distractors over the course of training. Former targets also failed to attract attention at transfer. Therefore, it is not the case that CM training invariably leads to automatic attention attraction. Of course, one must exercise caution when attempting to interpret a lack of effect, especially when the number of participants is small. On the issue of statistical power, it is worth mentioning that our Experiments 3 and 4 each involved twice as many participants as did Kyllingsbæk et al.'s (2001) Experiment 2. This level of power was sufficient to obtain a difference in d' across FTP and FTA conditions in Experiment 3. Kyllingsbæk et al. repeatedly obtained such a difference in four experiments, but all their experiments involved the same stimuli.

This context suggests that the results of Experiment 4 had to do with the composition of the stimuli. The stimuli of Experiment 4 were similar to those of Experiment 3 (which were copies of Kyllingsbæk et al.'s, 2001, original stimuli), except that they contained fewer distinctive line segments. Nonetheless, our modified stimuli were still very easily recognizable and identifiable. If attention becomes attracted by the general shape of the targets used during CM training, as claimed by Kyllingsbæk et al., our modified stimuli should also have come to attract attention in Experiment 4. The fact that they did not cast doubt on the hypothesis that the effects

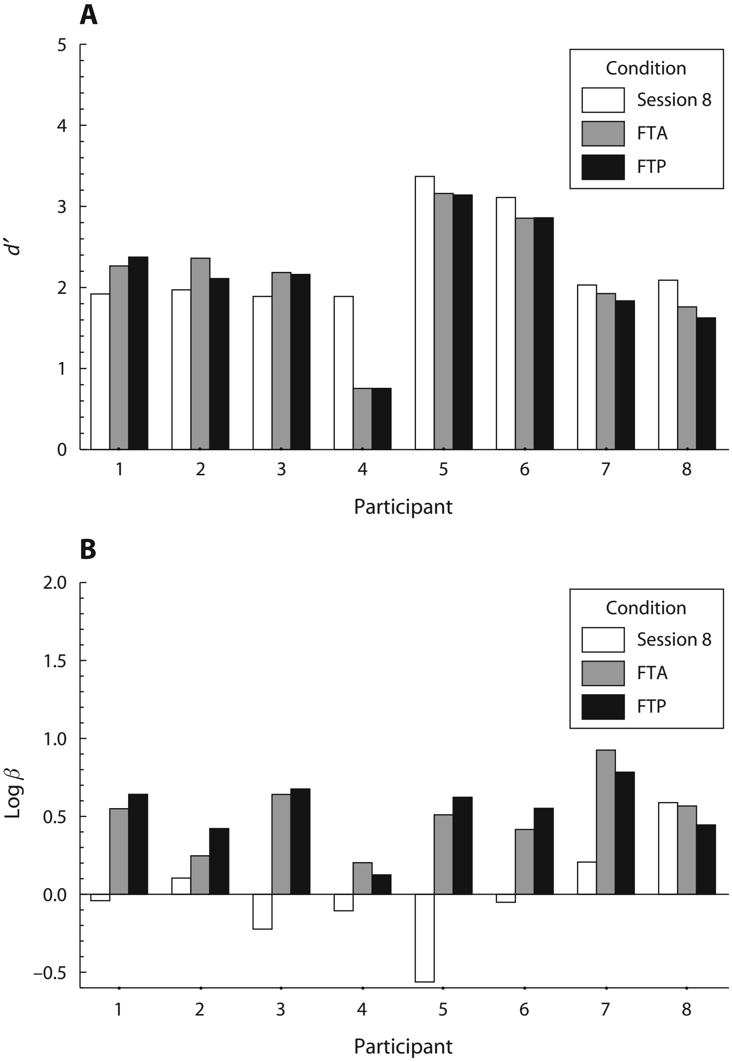

Figure 9. (A) *d′* at transfer for each participant in former target present (FTP) and former target absent (FTA) conditions of the VM transfer sessions, as well as the individual *d′*s obtained on the last CM training session of Experiment 4. (B) The corresponding log βs.

obtained in Experiment 3 and in Kyllingsbæk et al.'s experiments were driven by the global shape of the stimuli.

Czerwinski et al. (1992, Experiment 2C) did provide evidence that visual search could be driven by stimulus attributes more global than simple line segments. Each of their novel stimuli was composed of three straight-line segments of different position and orientation. The crucial aspect of their methodology is that every feature (defined as a line segment of a specific position and orientation) was found equally often among the stimuli serving as targets and distractors in both CM and VM conditions. Czerwinski et al.'s results showed visual search to improve much more in CM than in VM training conditions. Since this improvement could not be due to the featural composition of the stimuli (inasmuch as the features were line segments of specific position and orientation), Czerwinski et al. argued that CM training led to the integration of the features into a unitized object, whose global shape could then serve to drive search. It is worth noting, however, that each of Czerwinski et al.'s stimuli subtended more than 5° of visual angle and that the stimuli were displayed along the circumference of an imaginary circle subtending more than 41°. Under such peripheral viewing conditions, low frequency information conveying the spatial relationships among the stimulus components may indeed play a role in guiding search. Our results suggest that global or relational information may not have the same influence when more precise high-frequency featural information is available, as was the case under the more central viewing conditions of our experiments and of those of Kyllingsbæk et al. (2001).

GENERAL DISCUSSION

The general conclusion of the present study is that consistency of stimulus–response mapping is neither necessary nor sufficient to achieve optimal performance in visual-memory search. Target–distractor similarity appears to play a much more critical role. This does not mean, however, that consistency of mapping was completely without effect. In Experiment 2, search times decreased over the course of CM training, even though the targets and distractors were very similar. Target discriminability (d') also improved during CM training in Experiment 3. There follows a possible explanation of these effects.

In traditional VM conditions, all stimuli serve as targets on some trials and as distractors on others. Moreover, by contrast to CVM conditions, the stimuli are not grouped in different subsets. In such a case, the visual-memory search task can only be performed by comparing each item in the D set with the items in the M set on a given trial, thus the interactive effects of M set size and D set size. If the comparison process is self-terminating on positive trials, as proposed by S&S, the M × D interaction will be more pronounced on negative trials. Such large M × D × R interaction characterized performance on the first session in the CM conditions of Experiments 1 and 2.

The decrease in RTs observed in Experiment 2 was largely due to the fact that the effects of memory and display size stopped to interact with each other and with response type. Instead of comparing each item in the M set with each item in the D set on a given trial, participants may have come to rely on stable, long-term knowledge about the identity of the targets and of the distractors, which remained constant throughout CM training. Kramer, Strayer, and Buckley (1990) provided evidence that, with increasing practice in a CM search task, participants came to rely less on short-term memory. Another line of evidence in favor of such a strategic change is that the interaction involving memory size, display size, and response immediately reappeared at transfer in Experiment 2, when the stimuli serving as targets and distractors started to switch roles. In other words, when long-term knowledge about the identity of the targets and distractors became useless, participants seemed to have immediately returned to the item-by-item comparison process that characterized early performance.

CM training did not allow only strategic changes. It seems to have also influenced the efficiency of display search. Although performance deteriorated greatly in the transfer condition of Experiment 2, old targets remained easier to detect than new targets did, which suggests an increased sensitivity to old targets relative to new ones. What caused the increase in search efficiency? The stimuli used in the CM conditions of Experiments 1 and 2 were all composed of long versus short straight lines combined with open versus closed loops. The position of the lines and loops within characters was variable. The important point is that these position-specific lines and loops were not represented equally often among the target and distractor sets. Similarly, in Experiment 3, the position-specific line segments were not equally represented in both stimulus sets. Participants may have capitalized on such frequency differences. Fisher (1982, 1984, 1986) and Cousineau and Larochelle (2004) proposed that, through CM training, participants gradually become sensitized to the features that best discriminate the set of targets from the set of distractors, search being guided by feature diagnosticity. If CM training causes search to start with the most diagnostic features, target detection will become more rapid—hence the shorter display search obtained in Experiment 2 and the larger d's obtained in Experiment 3.

Cousineau and Larochelle's (2004) model incorporates an information reduction principle (Haider & Frensch, 1996), in that the comparison process is also limited to the features that suffice to discriminate the targets from the distractors. The amount of information reduction that is possible depends on the relative similarity of targets among themselves, on the relative similarity of distractors among themselves, and on the differences between targets and distractors, as suggested by Duncan and Humphreys (1989, 1992; Humphreys et al., 1989). Information reduction is minimal when all the features of the potential targets are also present among the potential distractors. Information reduction is maximal when a single feature is present in all potential targets and absent from all potential distractors. In this case, search performance is optimal, since only one feature test is needed to detect the presence of a target on a display.

The preceding suggests that, instead of being independent, the effects of stimulus–response mapping on search performance may be mediated by target–distractor similarity. Information reduction is possible in VM conditions, but it is severely limited. When the target and distractors used on a given trial are randomly drawn from the same set of stimuli, the features that are diagnostic of a target on a given trial will belong to a distractor on a different trial, so that a large number of features tests will be needed to discriminate a target from the distractors. In such cases, the number of feature tests required to detect a target may be the same as that required to identify it. Both target detection and identification require attentional resources.

All else being equal, a larger amount of information reduction is possible when the stimuli form different subsets, even when these subsets switch role as targets and distractors over trials, as in CVM conditions. The results obtained in the CVM condition of Experiment 1 show that target detection can be very efficient when a single feature allows one to distinguish the two sets. If this feature is shared by many potential targets, then the identification of the target will require further feature tests. In other words, target detection will require much less attention than will target identification. This view is consistent with Lachter, Forster, and Ruthruff's (2004) claim that there is "no identification without attention."

By ordering and reducing the number of feature tests performed, Cousineau and Larochelle's (2004) sufficient feature model could provide a reasonable account of the RT means and standard deviations obtained in different load conditions after VM, CVM, and CM training. This suggests that, by contrast to AAAT's early claim, there may not be a fundamental, qualitative difference between the search processes underlying CM performance and those underlying VM performance.

Returning to the question asked in the title of this article, we wish to argue that consistency of mapping does not invariably lead to automatic target detection. The preceding discussion suggests that the effects of consistent mapping on the efficiency of target detection are largely, if not entirely, mediated by target–distractor discriminability. This does not mean, however, that consistency of mapping has no effect at other stages of processing, such as memory or decision processes.

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NOTES

1. Throughout this article, we will use the abbreviation S&S to refer to the two studies taken together.

2. Although we will talk about open versus closed loop characters, we do not assume that the loop is the effective distinguishing feature. Other features, such as the number of loose line endings, also allow one to discriminate the open loop (three endings) versus closed loop (two endings) characters.

3. This condition would be more appropriately called *set varied mapping*, to avoid confusion with situations involving marked categorical differences among stimuli, such as the difference between digits and letters.

4. The results of a similar ANOVA performed on the overall RTs led to the same conclusion.

5. Similar analyses performed on Kyllingsbæk et al.'s (2001) own results showed the same to be true of their Experiment 2.

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