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Attention on autopilot: Past experience and attentional set

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What factors determine the implementation of attentional set? It is often assumed that set is determined only by experimenter instructions and characteristics of the immediate stimulus environment, yet it is likely that other factors play a role. The present experiments were designed to evaluate the latter possibility; specifically, the role of past experience was probed. In a 320-trial training phase, observers could use one of two possible attentional sets (but not both) to find colour-defined targets in a rapid serial visual presentation (RSVP) stream of letters. In the subsequent 320-trial test phase, where either set could be used, observers persisted in using their pre-established sets through the remainder of the experiment, affirming a clear role of past experience in the implementation of attentional set. A second experiment revealed that sufficient experience with a given set was necessary to facilitate persistence with it. These results are consistent with models of executive control (e.g., Norman & Shallice, 1986), in which "top-down" behaviours are influenced by learned associations between tasks and the environment.

Attentional set—a preparatory state of the information processing system that prioritizes stimuli for selection based on simple visual features—is a powerful tool that allows observers to solve efficiently the various visual search challenges they may be faced with at any particular moment. Much is known about the types of sets, or strategies, at the observers' disposal (e.g., colour, orientation, or motion; see Wolfe & Horowitz, 2004, for a recent review), but less is known about how these sets are chosen. What are the determining factors?

An intuitive—albeit simplistic—answer holds that observers always choose the attentional set that they think will optimize performance. One

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prediction that can be drawn from this "maximal efficiency" account is that observers should attempt to establish sets that prevent unnecessary processing of known-to-be irrelevant stimuli. For example, in a search for a vertical bar among horizontal bars, observers could engage in an attentional set for "vertical", so as to avoid interference by a salient item possessing no informative value regarding the target's location (e.g., a singleton bar that is red when the remaining bars are all grey). Indeed, many reports in the literature have documented successful avoidance of distraction from feature singletons that were not predictive of the target location (e.g., Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992; Jonides & Yantis, 1988; Theeuwes, 1990; Yantis & Egeth, 1999). However, several other reports have shown that known-to-be-irrelevant singletons sometimes do interfere with search (e.g., Bacon & Egeth, 1994; Theeuwes, 1991, 1992; Todd & Kramer, 1994; Turatto & Galfano, 2001). In some cases, patterns of seemingly inconsistent results have been obtained in essentially the same paradigm. For example, Folk et al. (1992) initially found that irrelevant green singletons interfered with search for red singletons in one experiment, but later work using similar stimulus conditions showed that observers effectively ignored the green singletons (Folk & Remington, 1998).

Why would observers sometimes adopt clearly nonoptimal sets that permit distraction by irrelevant items, if they are capable of more efficient behaviour? One possibility, suggested by Bacon and Egeth (1994), is that even when participants are capable of using attentional sets to avoid distraction, it is not necessarily their top priority to do so.

Following a speculation by Pashler (1988), Bacon and Egeth (1994) proposed two distinct attentional sets: *Singleton detection mode* and *feature search mode*. They described the former as a diffuse set that grants priority to the most salient information (e.g., feature singletons) in the visual field. Singleton detection mode does not discriminate between salience on the target's defining dimension and salience on other dimensions; thus, irrelevant singletons can capture attention when singleton detection mode is used. In contrast, Bacon and Egeth described feature search mode as a narrow attentional set that is limited to the target's defining feature; therefore, interference from salient information not matching the attentional set should be minimal. Bacon and Egeth speculated that singleton detection mode may be less effort-intensive to employ than feature search mode, so it may be appealing to tolerate a small decrement in search performance as a tradeoff with effort expended. Feature search mode, however, should be used when singleton detection mode would result in performance below some putative criterion of effectiveness.

To support their theoretical framework, Bacon and Egeth (1994) adapted a paradigm from Theeuwes (1991, 1992) that, in some experiments, yielded significant interference from irrelevant colour singletons while participants searched for shape singletons. Bacon and Egeth's implementation contained conditions where the shape targets were not singletons, which rendered singleton detection mode ineffective. Trials of these conditions were mixed within blocks with trials like those of Theeuwes where the targets were singletons, under the assumption that observers would maintain a feature search mode for the shape target across all trial types. Bacon and Egeth found that the colour-singleton distractors did not interfere in any of these conditions, including trials like those of Theeuwes where the target was a singleton, suggesting that feature search mode was used. These results supported the notion that participants were capable of adopting feature search mode in experiments such as those of Theeuwes, but they exhibited a preference for singleton detection mode in those experiments because such a strategy, although susceptible to more distraction than feature search mode, was still sufficient to locate the shape targets. Accordingly, Bacon and Egeth's results suggest that sets are not solely established to maximize performance. Rather, other factors may play a role.

Unfortunately, few subsequent research efforts have sought to reveal what factors are involved in determining attentional set (but see the section on intertrial contingencies in the General Discussion). In fact, it is often still assumed by researchers that the set of the observer should be based only on factors such as experimenter instructions or characteristics of the stimulus displays. These assumptions, however, are surely insufficient to predict the visual search strategies employed by observers, as evidenced by the contradictory findings in the attention capture literature. In this paper, we entertain the notion that additional forces are at work in determining the attentional set of observers.

Perhaps first acknowledging that attentional set is mediated by top-down control mechanisms can facilitate insight into how sets are determined. Research into executive control processes has long shown that human behaviour is not always optimal or straightforward.

Consider the classic "water jug" experiments carried out by Luchins and Luchins (Luchins, 1942; Luchins & Luchins, 1950; described in Woodworth & Schlosberg, 1960). Observers were asked to solve a mathematical word problem that involved measuring an exact quantity of water by using three separate jars of varying size. The first five trials could be solved by the same somewhat complicated algorithm. On the sixth, critical, trial that algorithm would still work; however, a considerably easier solution was also available. Luchins observed that observers not only continued to use the now inefficient routine on this critical trial, but they persisted with it for several more trials. As a result, it was concluded that "Einstellung", or "mental set", is not constantly evaluated to ensure that the most efficient strategies are carried out.

This notion that humans do not constantly evaluate their performance is central to modern models of executive control. One influential model, the "Attention to Action" model of Norman and Shallice (1986), assumes that behavioural routines, or "schemas", are carried out automatically, triggered by environmental cues (or the output of other schemas). For example, the repeated association between entering a dark room and reaching to the wall for the light switch eventually leads to a high activation level for the "turn on the lights" schema as one enters a darkened room. Evidence for such automatic influences on behaviour comes from many sources, but introspection is often the most compelling; most people can easily recall at least one anecdote where absent-mindedness led them to perform an action sequence against their goals (e.g., setting out to go to the grocery store on a Saturday and inadvertently driving all the way to work; for studies of such "action lapses" or "capture errors", see Norman, 1981; Reason, 1979, 1984). While automatic processes may be most evident when they lead to unintended actions, Norman and Shallice theorized that these processes are always at work. In effect, the influence of automatic processes could be pervasive, biasing actions toward a particular behaviour in each learned environment. Only when the output of a schema fails to reach behavioural goals within an acceptable range—which can happen, for example, when a new goal arises in a familiar environment—does an executive monitoring process (what Norman & Shallice call the "supervisory attentional system") take over to inhibit some schemas while preferentially activating others.

Do the properties of executive control, such as persistence with a pre-established strategy (as Luchins & Luchins observed), govern the implementation of attentional set? Or, alternatively, is attentional set always determined solely by current task demands and stimulus characteristics? In the present experiments, we studied the role of past experience. Observers participated in a training phase of visual search trials designed to encourage the use of a particular strategic behaviour (i.e., attentional set); one group of observers was required to use singleton detection mode while another group was required to use feature search mode. After training, all observers were treated in the same manner; a test phase of trials that could be adequately searched with either attentional set (singleton detection or feature search mode) was presented. Would performance in the test phase be influenced by the conditions of the training phase?

EXPERIMENT 1

In carrying out this study, some methodological concerns were addressed. First, the paradigm would need to contain conditions where more than one set was available to the observer. Second, it would need to incorporate a robust tool that could characterize the set used by the observer. The paradigm of Folk, Leber, and Egeth (2002) was deemed adequate to satisfy both of these requirements.

Folk et al. (2002) asked participants to monitor a rapid serial visual presentation (RSVP) of 15 letters at fixation for a single colour-defined target. These streams appeared at a rate of approximately 10 letters per second. In their first experiment, the target colour was consistent across trials (e.g., red), and nontargets were always grey. To find the target letter, either singleton detection mode or feature search mode could be used (the target was always unique with respect to the homogeneously coloured nontargets, making singleton mode a viable strategy, and its consistent colour made feature search mode for the specific target colour a viable set). Because two suitable sets were available on these trials, they can be referred to as *option* trials. Folk et al. were able to determine which set was used, by measuring the interference created by briefly presented peripheral distractors, which contained four pound-signs (i.e., "#"; see Figure 1). Three types of distractor displays were used (in addition to a no-distractor condition). In

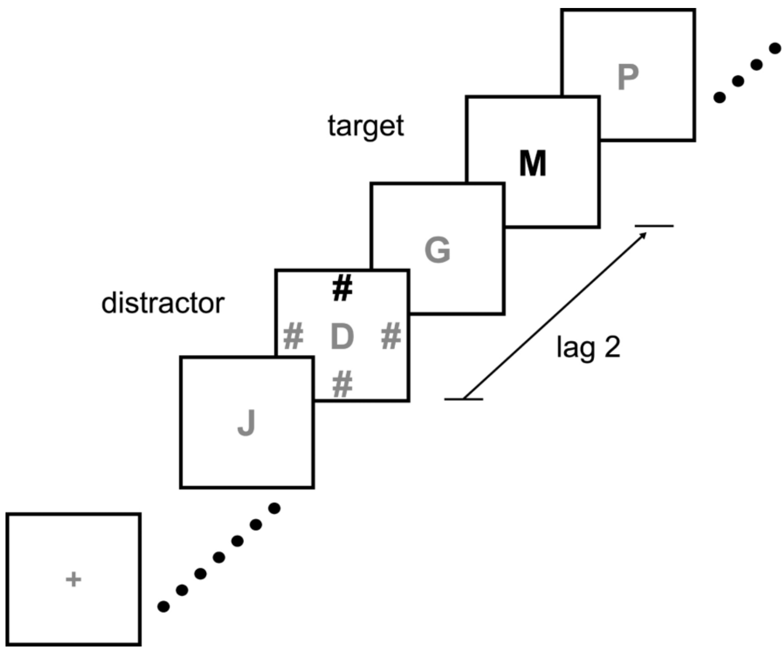

Figure 1. Representation of trial events in Experiment 1 of Folk et al. (2002). In this example, a distractor display containing a colour singleton appears at a "lag" of two items (approximately 200 ms) prior to the target. Black characters were coloured red or green (see text for details). Figure reprinted with permission of the Psychonomic Society.

the "all-grey" distractor display, all four "#"s were coloured grey. In the "same-coloured singleton" display, three "#"s were grey, and the remaining "#" was the same colour as the target (red or green). The "different-coloured singleton" display contained a singleton colour item that did not match the target colour (green or red, depending on the target colour). Folk et al. reasoned that if a singleton distractor could not be excluded by the attentional set, it would interfere with search performance (in comparison to the no-distractor and neutral all-grey distractor displays). They found that both same- and different-coloured singleton distractors interfered, and the cost was greatest at a distractor–target "lag" of two, that is, when the distractors were presented simultaneously with the letter appearing two frames (i.e., approximately 200 ms) prior to the target (see Figure 2, left panel). The fact that interference was created by both same- and different-coloured singletons suggested that singleton detection mode was used.

In a second experiment, Folk et al. (2002, Exp. 2) made the nontargets in the stream heterogeneous in colour. This manipulation rendered singleton detection mode ineffective (the target did not stand out as a singleton), so it was predicted that feature search mode would be adopted. The results confirmed this prediction; interference from same-coloured distractors was not observed in comparison to the all-grey condition (although both all-grey and different-coloured singletons were slightly worse than the no-distractor condition), while target-coloured distractors significantly impaired performance (see Figure 2, right panel). Similar to what Bacon and Egeth (1994) showed with static displays, participants in temporal search tasks (i.e., RSVP) tended to operate in singleton detection mode when given the option.

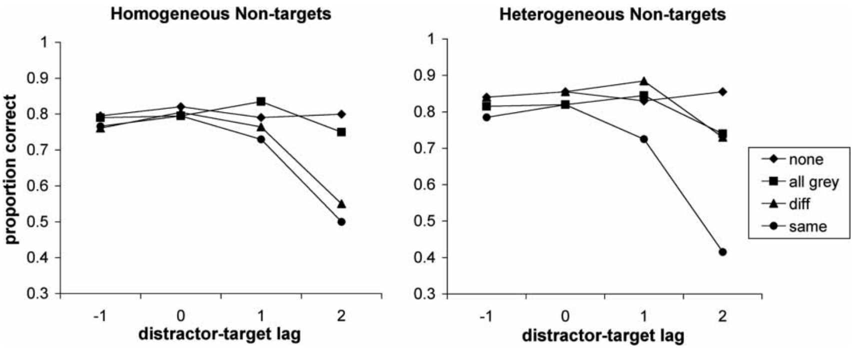

Figure 2. Data from the first (left) and second (right) experiments of Folk et al. (2002). Mean proportion correct is plotted as a function of distractor–target lag, by distractor condition. "None" refers to trials where no distractors were presented. All peripheral "#" items were grey on "all-grey trials", one of the four items was a nontarget-coloured singleton on "diff" trials, and one of the four items was a target-coloured singleton on "same" trials; see text for additional details. Reprinted with permission of the Psychonomic Society.

However, when singleton detection mode was rendered ineffective, they exhibited the ability to use feature search mode.

The paradigm of Folk et al. (2002) was used in the present experiments to determine if past experience could influence an observer's attentional set. In these experiments a "test phase" of option trials (e.g., like those used in Experiment 1 of Folk et al., 2002) was preceded by a "training phase" containing one of two trial types: One group of observers was influenced to use feature search mode for roughly 30 minutes while another group of observers was influenced to use singleton detection mode. To encourage feature search mode in the former group, observers were exposed to a block of practice trials in which they searched for a target of a known colour among heterogeneous nontargets (similar to Folk et al., 2002, Exp. 2). To encourage singleton detection mode in the latter group, observers were required in practice trials to search for targets of randomly varying colour embedded among grey nontargets (feature search mode would be ineffective, since target colour was unpredictable). Additionally, the distractor–target lag was held constant at two on all trials; since the present aim was to determine which sets were used, the lag known to yield the largest interference was chosen.

The analysis focused primarily on the test phase trials (i.e., the option trials), which were identical for both groups of observers. If past experience influences current attentional set, then participants should maintain the set used in the training phase throughout the option trials in the experimental trials. Alternatively, if attentional set is based solely on the current task demands and stimulus environment, then both groups of participants should ultimately converge upon the same set in the experimental trials, regardless of the set used during practice trials. Note that this latter alternative is agnostic as to what set should be converged upon; the key question was whether convergence would occur at all.

Method

Participants

Forty-eight Johns Hopkins undergraduates with self-reported normal or corrected-to-normal visual acuity and normal colour vision participated in a session lasting approximately 50 minutes.

Materials

Stimuli were generated with a personal computer and displayed on a 19 inch VGA monitor. Participants stabilized their heads with a chinrest placed at a viewing distance of 55 cm. Letters from the English alphabet (excluding

I, O, W, and Z), used for RSVP streams, were 1.0° tall × 1.0° wide with a stroke of 0.3°; each letter, depending on variables described below, was grey, blue, purple, green, or red. When present, "#" distractors (1.0° tall, 1.0° wide, stroke = 0.3°) were centred 5.2° above, below, to the right, and to the left of fixation; they were grey, red, or green. All stimuli were presented on a black background.

Design

The experiment consisted of a *training phase* and *test phase* for all observers. For the training phase, half of the observers were assigned to the "feature group"; the remaining observers were assigned to the "singleton group". During the test phase, all observers—irrespective of training assignment—were treated similarly. Within each group, *colour assignment*, a variable that was used to determine the observer's target colour, was counterbalanced between observers; half of the observers were assigned "red" and the remaining observers were assigned "green".

For both groups (singleton and feature), and within each phase, three independent variables were manipulated within observers to determine the stimulus characteristics on each trial: *Distractor type* (four levels), *singleton location* (four levels), and *temporal distractor position* (five levels). This yielded 80 unique conditions, which were each presented four times in each phase for a total of 320 trials per phase; presentation order was randomized within each phase. Variables are described as follows.

- *Distractor type*. On 25% of the trials, no distractors were presented. On the remaining trials, one of three displays was presented (each 25% of the trials), which are described as follows. The "all-grey" display contained four grey "#"s. The "same-coloured singleton" display contained three grey "#"s and one "#" that matched the colour assignment (red or green, depending on the observers' colour assignment); and the "different-coloured singleton" display contained three grey "#"s and one nontarget-coloured "#" (green or red, depending on the observers' colour assignment).
- *Singleton location*. Singleton distractors (i.e., the uniquely coloured peripheral distractors), when present, appeared equally often at each of the four peripheral distractor locations.
- *Temporal distractor position*. The distractor display was presented simultaneously with the letter occupying one of five serial positions (10–14, each used equally often) in the stream. The position of the target item in the stream depended on the distractor position, as it always appeared two positions later. On no-distractor trials, distractor position was "dummy coded" to keep target position balanced.

Training phase. Depending on group assignment, observers were exposed to one of two *stream types*. (1) Observers in the feature group searched for a target of consistent colour every trial (red or green, depending on colour assignment), which was embedded in a stream of heterogeneous nontargets (grey, blue, purple, and green); the colour of each nontarget stream letter in these trials was selected randomly with replacement. (2) Observers in the singleton group searched for a target that on a given trial could be any one of five colours selected randomly with replacement. One colour was determined by the observers' colour assignment (red or green); the remaining colours were purple, blue, yellow, and orange for all observers. The target colour on each trial was unannounced to observers; thus, it was unpredictable. The nontargets in the stream, for the singleton group in this phase, were all homogeneous in colour (grey) on every trial.

Note that for the singleton group, the colour assignment variable only determined the target colour on one-fifth of the trials. (It is in the nature of the singleton detection condition to present several unpredictable targets so that observers are forced to adopt a singleton detection mode.) However, the use of colour assignment to determine *one* of the possible target colours affords a comparison between two theoretically interesting distractor types. Consider an observer whose set of possible targets includes, say, red. On some trials this observer will be shown a peripheral distractor display that contains a red "#"; this is referred to as the "same singleton" condition because the coloured "#" is the same as one of the colours in the set of possible target colours. On some other trials this observer will see a peripheral distractor that is green; this is referred to as the "different singleton" condition. Note that for this observer green is never the target.

Test phase. All observers were presented with "option" trials in this phase. In these trials, a consistently coloured target was embedded in a stream of homogeneously coloured (grey) distractors. The target colour, determined by the colour assignment variable, was the same in the test phase as it was for the training phase; for example, an observer in the feature search group who had searched for red targets in the training phase would continue to search for red targets in the test phase.

Procedure

Participants were instructed to identify a target, defined by colour, that was embedded in a rapid stream of letters at the fixation location. During the training phase, observers in the singleton group were instructed to search for the uniquely coloured item in the RSVP stream, whereas observers in the feature group were instructed to search for the red (or green) item in the stream. In the test phase, all observers were informed that the target would be consistently coloured (i.e., red for some observers or green for other observers) for the remainder of the experiment. All observers were asked to report the target's identity by entering the correct letter into a computer keyboard after the completion of the RSVP stream. Also, they were informed about the peripheral distractors and told to ignore them. Accuracy was emphasized (speeded responses were not necessary, nor could they be advantageous, since responses were only accepted after the completion of the RSVP stream). The experiment consisted of 24 practice trials, followed by 320 training phase trials, which were in turn followed by 320 test phase trials. After the practice trials, breaks were given every 40 trials (including one between the two phases).

Trials were initiated by a spacebar press, which prompted a blank-screen presentation for 1000 ms. A white fixation cross was then presented for 500 ms, followed by a 200 ms interstimulus interval. Next, the RSVP stream consisting of 20 letters began. Each letter was selected randomly without replacement from the 22-letter set and presented for 50 ms, followed by a 50 ms blank interval, yielding a rate of 100 ms/letter. At the completion of the RSVP stream, participants were prompted to report the target letter. A 250 ms feedback tone was presented for incorrect responses.

Results and discussion

To determine the use of set, the approach was to measure the interference caused by the singleton distractors by comparing them to the all-grey condition (which was deemed the most appropriate baseline following the results of Folk et al., 2002); thus the no-distractor condition was not analysed (however, it is included with the plotted means).

Training phase. Data from the training phase were analysed to determine if the experimental manipulation succeeded in inducing the observers in the two groups (feature and singleton) to adopt divergent sets.

For the feature group, mean accuracy scores in the four conditions (none, all-grey, same singleton, and different singleton) were 77%, 69%, 59%, and 72%, respectively. Two-tailed t-tests showed that performance on same singleton trials was worse than in the all-grey condition, $t(23) = 4.238$, $p < .001$; performance on different singleton trials was not different than on the all-grey trials, $t(23) = 1.440$, *ns*. Additionally, performance on the same singleton trials was worse than on the different singleton trials, $t(23) = 4.873$, $p < .001$. The selective interference by only the target-coloured distractor indicates that feature search mode was used on these trials.

For the singleton group, mean accuracy scores in the four distractor conditions (none, all-grey, same singleton, and different singleton) were 86%,

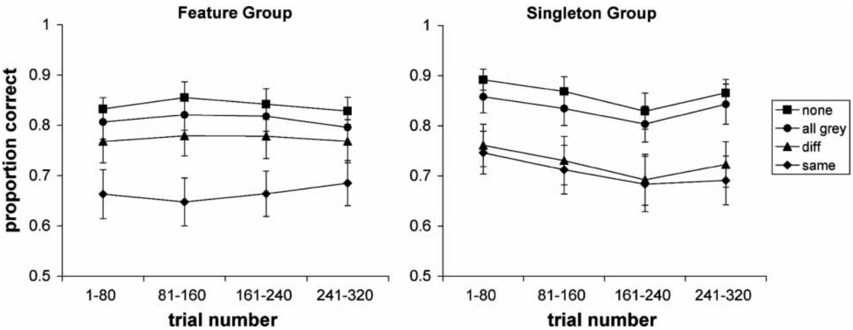

Figure 3. Performance on the test phase of Experiment 1. Left: Mean proportion correct for the feature group as a function of distractor type and trial number (placed into four bins of 80 trials). Right: Mean proportion correct for the singleton group.

83%, 68%, and 65%, respectively.[1] Performance on both "same" and "different" conditions was worse than in the all-grey condition: $t(23) = 4.917$, $p < .001$, and $t(23) = 5.038$, $p < .001$, respectively. Additionally, performance in the "same" and "different" singleton conditions did not differ significantly, $t(23) = 1.852$, *ns*. The observation that both singletons worsened performance suggests that singleton detection mode was used on these trials.

Test phase. Data from the test phase were plotted in bins of 80 trials to observe potential gradual changes in set over the 320 option trials (see Figure 3). The data were first analysed within each training group assignment to determine how attentional set was used (while collapsing across bin).

In the feature group, observers appeared to continue using feature search mode on the option trials; whereas the difference between performance on different singleton and all-grey trials was nonsignificant, $t(23) = 1.911$, performance was markedly worse on same singleton trials than on both all-grey trials, $t(23) = 5.249, p < .001$, and different singleton trials, $t(23) = 4.730$, $p < .001$. In contrast, observers in the singleton group appeared to continue using singleton detection mode on the option trials; performance was worse on both same and different singleton trials than the all-grey baseline, $t(23) = 4.227$, $p < .001$, and $t(23) = 4.185$, $p < .001$, respectively, and no difference was observed between same and different singleton trials, $t(23) = 0.907$, *ns*.

[1] The reader is reminded that "same" and "different" singleton conditions should be interpreted in the proper context, for the singleton group, during the training phase; the "different" singleton distractor never matched the colour of the target, but the "same" singleton distractor matched the actual target colour 20% of the time, as the target could be one of five colours.

Two more questions were probed within the test phase data. First, it was necessary to determine if the patterns of distractor interference in the test phase differed significantly between training phase groups. The second question concerned whether the patterns of interference changed throughout the course of the test phase. For both training groups, and within each bin of 80 trials, we computed distractor interference effects for both same and different distractor conditions. This was done by subtracting the accuracy scores for each of the respective distractor conditions from that of the all-grey condition. The resulting interference cost data were subjected to a three-factor mixed model ANOVA, which included *singleton condition* (two levels: same and different, *bin* (four levels), and *training group assignment* (two levels: feature and singleton). Speaking to the first question, it appears that the two groups used disparate sets during the test phase, as the interaction between training group assignment and singleton condition was significant, $F(1, 46) = 9.391$, $MSE = 0.200$, $p < .005$. Regarding the second question, observers did not significantly change their sets during the test phase, as no main effect of bin was observed, $F(3, 138) < 1$, nor did it enter into any interactions.

The results are clear. Set was not determined solely by the current task demands and stimulus environment. If such were the case, then both groups would have converged upon the same set. Rather, both groups persisted in using their respective training-phase sets for the 320 option trials of the test phase.

EXPERIMENT 2

Experiment 1 provided compelling evidence—in the form of an effect of past experience—that attentional set is not determined only by factors such as the immediate stimulus environment. On the heels of this result, however, comes a new question. *How* does past experience influence attentional set? We considered earlier that automatic control factors could be responsible (Norman & Shallice, 1986). However, one may question whether the results of Experiment 1 are truly indicative of automatic control over attentional set; rather than persisting because they failed to reevaluate their sets in the test phase, it is possible that observers simply decided consciously not to change their strategies. This would be plausible if, perhaps, the difference in the subjective desirability of feature search mode and singleton detection mode on the option trials was so negligible to observers that switching to the most preferred set would not have been worth the effort of reconfiguring attentional set (for evidence of costs for switching attentional set, see Hillstrom, 2000; Leber & Egeth, 2001).

Experiment 2 evaluates the role of automatic control in the persistence of attentional set. On the account that observers evaluated their current task demands and voluntarily chose not to reconfigure attentional set, one should expect that they would persist with a pre-established set regardless of their amount of experience with using it. The alternative, however, is that attentional set is influenced by automatic factors, which can be strengthened, with more experience with one set, to bias the automatic activation level of one set over another (e.g., as the model of Norman & Shallice, 1986, would predict). On this account, the duration of the training phase should influence how likely observers are to persist in the test phase.

In the present experiment, the duration of the training phase was reduced to 40 trials. Observers were expected to achieve their required sets by the end of the training phase (i.e., feature search mode or singleton detection mode, depending on group assignment); the question was whether they would persist with them in the test phase.

Method

Participants

Thirty-six Johns Hopkins undergraduates with self-reported normal or corrected-to-normal visual acuity and normal colour vision participated in a session lasting approximately 35 minutes.

Materials, design, and procedure

This experiment was identical to Experiment 1, except the training phase was dramatically reduced; instead of 24 practice trials followed by a 320 trial training phase, observers only received 40 total trials of training; these trials were each sampled randomly without replacement from the 80 unique conditions generated by crossing *distractor type* (four levels), *singleton location* (four levels), and *temporal distractor position*. After training, all subjects participated in the 320 trial test phase.

As in Experiment 1, half of the participants were assigned to the feature group, and the other half were assigned to the singleton group. Additionally, within each group, half were assigned the target colour red and the other half were assigned the target colour green.

Results and discussion

Training phase. An examination of the means (excluding the first 10 trials, during which familiarization with the task likely was taking place), confirms that the expected sets were used.

For the feature group, mean accuracy in the four distractor conditions (none, all-grey, same singleton, and different singleton) was 80%, 79%, 54%, and 77%, respectively; *t*-tests revealed that performance on same singleton trials was worse than in the all-grey condition, $t(17) = 4.035$, $p < .001$; performance on different singleton trials was not different than in the all-grey trials, $t(17) = 0.819$, *ns*. Additionally, performance on the same singleton trials was worse than on the different singleton trials, $t(17) = 2.724$, $p < .02$.

For the singleton group, mean accuracy in the four distractor conditions (none, all-grey, same singleton, and different singleton) was 86%, 78%, 51%, and 46%, respectively. On both "same" and "different" singleton conditions, performance was worse than in the all-grey condition: $t(17) = 3.719$, $p < .002$, and $t(17) = 5.050$, $p < .001$, respectively. Additionally, performance in the "same" and "different" singleton conditions did not differ significantly, $t(17) = 1.227$, *ns*.

Test phase. Data from the test phase were analysed in the same fashion as Experiment 1; mean accuracy scores are plotted in Figure 4.

In the feature group, data are not easily categorized as indicative of either feature search mode or singleton detection mode. On the one hand, performance was worse in same and different singleton conditions than in the all-grey condition, $t(17) = 5.518$, $p < .001$, and $t(17) = 2.994$, $p < .01$, respectively. On the other hand, performance in the same singleton condition was worse than in the different singleton condition, $t(17) = 4.050$, $p < .001$.

Data were similar in the singleton group. Performance in the same and different singleton conditions was worse than in the all-grey condition, $t(17) = 4.962$, $p < .001$, and $t(17) = 4.262$, $p < .01$, respectively. Also, same

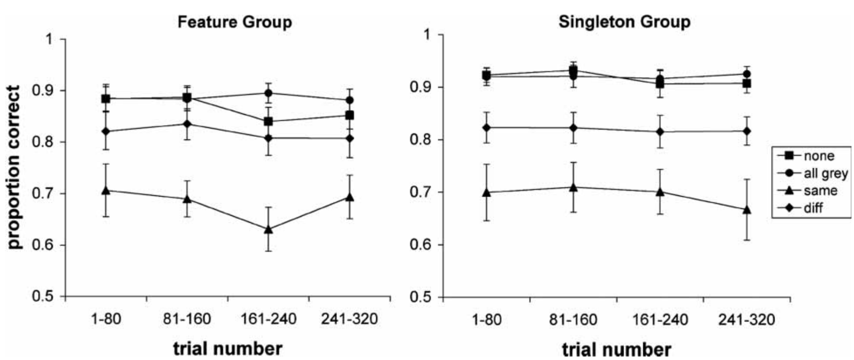

Figure 4. Performance on the test phase of Experiment 2. Left: Mean proportion correct for the feature group as a function of distractor type and trial number (placed into four bins of 80 trials). Right: Mean proportion correct for the singleton group.

singleton performance was worse for same singleton distractors than different singleton distractors, $t(17) = 4.026$, $p < .001$.

Performance did not vary as a function of bin, as this variable did not yield a significant main effect and did not enter into any significant interactions (all *F*s < 1) in the *singleton condition* (2 levels) × *bin* (4 levels) × *training group* (2 levels) ANOVA. Additionally, the pattern of singleton costs did not significantly vary as a function of training group, as this interaction was not significant, $F(1, 34) < 1$.

Apparently, the separate treatment of the two groups of observers during the shortened training phase failed to significantly influence their performance in the test phase. Even though the patterns of distractor interference from the training phase showed that observers entered the test phase using divergent sets, the observers did not carry these divergent sets forward into the test phase. Thus, it appears that the likelihood of persistence is dependent on how much experience one has with a given set. This result is consistent with the notion that automatic processes, which are built upon past associations between the environment and relevant tasks, play a role in the implementation of attentional set.[2]

GENERAL DISCUSSION

We set out to explore the determining factors of attentional set. In particular, the role of past experience was probed, and the results revealed that sufficient past experience exerted a strong influence on attentional set; it caused observers to maintain divergent sets under identical stimulus conditions for up to 30 minutes (i.e., 320 trials), with no sign of subsiding. However, in line with influential models of executive control (e.g., Norman & Shallice, 1986), observers needed sufficient experience with a given set in order to persist with it; Experiment 2 revealed that after two groups of observers entered disparate sets in a training phase, they did not maintain them during the test phase.

Our work is not the first to assert a relationship between past experience and attentional set. For example, Müller and colleagues (e.g., Found & Müller, 1996; Müller, Heller, & Ziegler, 1995; see Müller & Krummenacher, 2006 this issue, for a review) have shown that visual search for feature singleton targets is faster when targets in the previous trial "pop out" on the same dimension as the target on the current trial, compared to when targets

[2] We acknowledge a limitation in drawing strong conclusions favouring our automaticity account from the results of Experiment 2 alone, as alternative explanations could account for our data. For example, an observer's subjective assessment of the costs of switching to a new set could increase as a function of experience with the old set.

in previous trials pop out on a different dimension. This phenomenon of dimensional "intertrial facilitation" may suggest that top-down attentional set is reconfigured to prioritize defining feature dimensions based on recent stimuli (see Krummenacher, Müller, & Heller, 2003; Olivers & Humphreys, 2003; Wolfe, Butcher, Lee, & Hyle, 2003). However, it has also been argued that these effects reflect benefits/costs at postselection decision or response stages of processing (e.g., Feintuch & Cohen, 2002; Kumada, 2001; Theeuwes, Reimann, & Mortier, 2006 this issue). Such "response priming" effects would be unrelated to attentional set. Researchers have not yet reached a consensus on the level at which dimensional effects occur and, in fact, the debate is still quite lively.

In addition to the dimensional effects are feature-specific intertrial modulations, which arise when targets on previous trials either share or do not share the specific feature value (e.g., red or vertical) with the current target ("priming of pop out"; Maljkovic & Nakayama, 1994, 2000). While these effects may be viewed as simply acting at a more specific level of the same hierarchy as the dimensional effects, they differ qualitatively in several ways. For example, when observers have to make a discrimination about a property that is orthogonal to the target's defining pop-out characteristic (e.g., if the object has a "chip" in the left or right side), the dimensional effects can be weak while feature priming effects remain intact (see Kumada, 2001; Theeuwes et al., 2006 this issue; but see Müller & Krummenacher, 2006 this issue; Pollmann, Weidner, Müller, & von Cramon, 2006 this issue). Thus, even if the dimensional effects are not related to attentional set, one might question whether feature-specific effects are related. However, one central finding that is at odds with such speculation is that feature-specific priming appears to be dissociable from top-down expectancies (Maljkovic & Nakayama, 1994, 2000). This characteristic of the phenomenon separates it from attentional set, where observers are capable of dramatically reconfiguring their preparedness from trial to trial, albeit with some costs (e.g., Leber & Egeth, 2001).[3]

All things considered, the present work is most distinct in *duration* from the intertrial effects, whose temporal range does not exceed more than a few trials. The central reason our effects persist for so long is that observers in this study (Experiment 1) are influenced to use a particular attentional set—a strategy determined by executive control functions—in the test phase; such strategies, although influenced by experience, are clearly not directly

[3] While we view priming as a phenomenon that is distinct from attentional set, we do not think that one has to reject the possibility that it operates in a top-down manner. Granted, priming may not be determined by expectancy, but it is not clear that this should be taken as a defining characteristic of a top-down process.

determined by the immediate stimulus, or even stimuli from the very recent past.

We find a link between these results and studies of "contextual cueing" (e.g., Chun, 2000; Chun & Jiang, 1998), where search performance benefits when associations between invariant display properties (e.g., spatial layouts of search items) and target properties (e.g., location or identity) are learned implicitly by observers.

In sum, the observations in the present experiments support the notion that observers do not continually evaluate their chosen sets based on current task demands and stimulus characteristics. If they had done so, they would have converged upon similar sets in Experiment 1. Rather, automatic control processes are likely at work. These results carry methodological and theoretical implications for research on attentional set, as they demonstrate that the set of an observer cannot be inferred by solely evaluating his/her real-time sensory input and task demands. Owing to their past experience, observers in this study used divergent sets under *identical* stimulus conditions with *identical* task requirements. While these results were observed in the context of a highly controlled laboratory experiment, they are consistent with the notion that any attentional set used by a participant at the beginning of an experiment can be influenced by a wide range of events—specific to that individual—occurring prior to the testing session. Efforts to further explore how past experience influences attentional set may succeed not only in reconciling inconsistent findings in the attention capture literature, but in facilitating a broader understanding of the properties of attentional control.

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