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Attentional shifts to rare singletons

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Five experiments examined whether extremely rare featural singletons (e.g., presented in 4% of all trials) capture attention, and whether this effect could be explained by top-down contingent capture or stimulus-driven singleton capture. To this end, performance (accuracy in Experiments 1–4, reaction time in Experiment 5) in a demanding letter search task was measured in singleton trials that were presented within rare-singleton blocks consisting mainly of no-singleton trials, and in singleton trials that occurred in all-singleton blocks. In separate blocks, either target singletons (i.e., a singleton at target position), or distractor singletons (i.e., a singleton at a distractor position) were presented in each trial. Results are consistent with the contingent-capture view. When the letters were presented briefly and accuracy was the dependent variable, a large performance benefit was obtained, revealing that attention was shifted very fast to the singleton. An examination of search efficiency with a variation of set size and reaction time as the dependent variable revealed a strong gain in search efficiency with a rare target singleton. The large benefit was not accompanied by proportionally large costs for distractor singletons relative to the no-distractor trials. Moreover, a comparison of singleton trials from the all-singleton and from the rare-singleton blocks revealed nonspatial costs for the rare singletons that were of about the same size for target and distractor singletons. In summary, results show that an attentional control setting can remain "dormant" for many trials where it is not applicable, but is then applied nearly as efficiently as when the control setting has been used just recently.

How do we find objects that we look for? Finding an object that is defined by a certain conjunction of features that also appear separately in the objects' surroundings normally requires an effortful search (e.g., Treisman & Gelade, 1980; Wolfe, 1998). That is, attention has to be deployed to possible object locations in a serial manner. In contrast, if we look for an object that

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is a feature singleton—that is, a stimulus defined by a basic perceptual feature that is unique to the singleton relative to the encompassing, more homogenous surroundings (e.g., a red item among green items)—an active search is not necessary and the singleton object can be attended to at once (e.g., Yantis & Egeth, 1999). According to the contingent-capture hypothesis, an attentional control setting can be established "offline", that is, before the stimulus appears, to features that discriminate between the relevant target stimulus and the irrelevant distractors. As a consequence, when a stimulus appears that matches the set of searched-for features, attention is quickly drawn to that stimulus (e.g., Ansorge & Heumann, 2003, 2004; Folk, Remington, & Johnston, 1992). Correspondingly, participants can willingly set their control settings to search for a singleton if singleton search helps to find the target (cf. Bacon & Egeth, 1994).

The present study asks whether an attentional control setting for colour can be maintained for a substantive number of trials in which the setting is not applicable. In particular, it is tested whether a colour singleton can be attended to quickly when presented only occasionally (in some but not all trials of a block) during a visual search task for a conjunction target (i.e., a letter defined by a conjunction of horizontal and vertical line segments). Evidence concerning attention to a rare singleton is scarce: Yantis and Egeth (1999, Exp. 9) presented displays that frequently (80%) or rarely (20%) contained a distractor singleton (i.e., a singleton that never occurs at the position of the target) to different groups of participants. Their results indicated that the distractor singleton was completely ignored: Performance (time to find the target) in the no-singleton trials did not differ from performance in singleton trials. This result suggests that nonpredictive rare events do not draw attention.

Because Yantis and Egeth (1999) presented singletons at a distractor position only, there was no incentive to set the attentional control settings for the singleton or its specific features. Therefore, their experiment does not clarify whether a control setting to attend to a certain feature or to a singleton can be maintained across a large number of trials without a matching input, and whether participants would adopt such a control setting. These questions can only be studied by the use of rare but predictive target singletons (i.e., singletons presented at target position). With respect to the findings of Yantis and Egeth, it is first conceivable that the long-term maintenance of a particular control setting is impossible or is too error-prone. For example, it might be that such a setting is dropped without a matching input due to the relatively automatic decay of the corresponding working memory traces. Second, given that it is possible to maintain the control setting, the benefits of attending to a rare target singleton might be lower than the costs that are incurred by the implementation and the maintenance of the top-down setting for the singleton so that the corresponding control setting is voluntarily dropped (e.g., Yantis & Egeth, 1999). By analogy, one could regularly synchronize the departure time by car with that of the public busses to get to work on time even if the car breaks down; however, a breakdown of the car is so rare that it does not pay to check the corresponding parameters (bus departure times) regularly. To summarize the predictions, if it can be shown that participants can make use of a rare but predictive target singleton, the implication is that the maintenance of top-down control settings for attentional shifts is both possible and scarcely demanding.

THE PRESENT EXPERIMENTS

The present experiments examined attentional shifts to frequent and to extremely rare singletons that were either predictive of the position of the target (target singleton) or that were always presented away from the target and, thus, nonpredictive of the target (distractor singleton). More precisely, rare-singleton trials occurred in only 1 out of 25 trials at an unpredictable serial position within the sequence of trials in Experiments 1, 2, and 3, in 1 out of 25 or 1 out of 13 trials in Experiment 4, and in 1 out of 9 trials in Experiment 5. That is, the singletons were much rarer in the present experiments (e.g., 4% in most experiments) than in Yantis and Egeth's Experiment 9 (i.e., 20%). Participants were fully informed about the contingencies that existed between the singleton's and the target's position and about the singleton's probability. For example, in Experiment 1, participants were informed that the singleton in the upcoming block of trials, if present, either always (target-singleton block) or never (distractor-singleton block) indicated the position of the target. Both target and distractor singletons appeared either in all-singleton blocks, with a singleton (and several nonsingletons) in each trial, or in rare-singleton blocks, with singleton trials (consisting of a singleton and several nonsingletons) separated by randomly varying numbers of no-singleton trials (consisting of nonsingletons only).

A search task was used in which the participants determined which of two target letters appeared among 11 distractor letters, with letter positions varying randomly from trial to trial. In all experiments but the last, the letters were presented briefly (for 86 ms), and accuracy was the dependent variable. Due to the restricted presentation time and the unknown position of the target, this task is relatively difficult and the target, demanding a serial or effortful search, cannot be detected on every no-singleton trial. In contrast, if the target position is singled out by colour, which is the case in the target singleton conditions, position uncertainty is eliminated, and instead of a serial search, attention can be shifted directly to the target singleton. Thus, shifting attention to a target singleton is expected to improve performance (i.e., to help find the target more frequently) relative to the baseline conditions without a target singleton (no singleton conditions). In Experiments 1–4 accuracy was used as the dependent variable for two reasons. First, we were interested in the time course of attentional shifts (see also Horstmann, in press): By varying the interval between the presentation of the singleton and that of the trailing (temporally restricted) target letter display, it is possible to test how fast attention is shifted to the singleton, and whether the effect of the deployment of attention on the perception of the target letters changes as a function of the singleton-target interval. With an interval of zero (i.e., concomitant onsets of singleton and target letter), for example, only very rapid shifts of attention would allow for a significant improvement of target letter perception. By further increasing the interval it is then possible to check whether target perception further increases, which would be the case if the duration of the target letter display were too brief to bail out the full attentional effect. Second, we wanted a relatively pure measure of the attentional deployment that is not possibly inflated by additional processes that register in RT (e.g., Gibson & Jiang, 1998; Huang & Pashler, 2005). However, because results and conclusions with accuracy and RTs might not be the same, Experiment 5 complemented the preceding experiments by measuring RTs.

The design of the present study allows for a number of tests. First, the question of whether attention is quickly allocated to a rare singleton is tested by comparing performance between singleton and no-singleton displays in rare-singleton blocks with a target singleton. If attention is quickly shifted to the singleton's position, performance should be better with a target singleton compared to the no-singleton displays. Second, the question of whether attention is allocated with comparable efficiency to rare and to frequent singletons is tested by comparing performance in trials with a target singleton in all-singleton blocks (frequent singletons) and rare-singleton blocks (rare singletons). Third, in order to test whether attention is in fact allocated quickly, short SOAs (stimulus–onset asynchronies, i.e., intervals between the onset of the singleton and that of the target) were used. In particular, with 0 ms SOA of the singleton and the search display, and the restricted presentation duration of the search display (86 ms), only very fast attentional shifts can improve performance. In addition, positive SOAs were used in Experiment 2 in order to test whether providing more time would give additional benefits. Fourth, because it has been proposed that a singleton captures attention even in the absence of a corresponding intention (e.g., Kim & Cave, 1999; Theeuwes, 1992, 1994), we tested whether a distractor singleton impaired performance in rare-singleton blocks. Finally, a comparison of the attentional effects of rare and of frequent distractor singletons allows us to test whether a distractor singleton has a stronger attention grabbing potential, for example, because it is unique both in space and time.

EXPERIMENT 1

Experiment 1 tested for attentional shifts to rare singletons with a 0 ms SOA, where performance could benefit from very fast shifts only. There were two types of blocks, all-singleton blocks, in which a colour singleton appeared in each trial, and rare-singleton blocks, in which only 4% of the trials contained a singleton, whereas 96% of the trials consisted only of no-singletons (i.e., were colour homogeneous). In a given block, the singletons—if present—were presented consistently at the target's position (target singletons), or at a distractor's position (distractor singletons). Participants were always informed in advance about the frequency of the singleton and whether the singleton was always a target singleton or whether it was always a distractor singleton, and they were instructed to attend to the target singleton and to ignore the distractor singleton.

Method

Participants. Eight students or visitors at Bielefeld University participated in partial fulfilment of study requirements or for payment (€6 per hour).

Apparatus. ERTS (BeriSoft Cooperation), run on a microcomputer equipped with an 80486 CPU, was used for event scheduling and data registration. A 15 inch colour monitor was used for stimulus presentation and a standard keyboard served to register the responses.

Stimuli. Each trial consisted of three displays (see Figure 1). All displays had a black background. The first display contained a fixation cross in the middle of the screen. The second display contained 12 coloured squares plus 12 letters. The coloured squares ($1.2^\circ \times 1.2^\circ$; viewed from a distance of 57 cm) appeared at the 12 hour positions of an imaginary circle (centred on the screen) with a radius of 3.4°. The 12 black letters ($0.7^\circ \times 0.8^\circ$) were presented centred inside the squares. In each trial, 11 different distractor letters (digital-clock-symbol like letters, similar to the letters A, B, C, D, E, F, I, J, L, P, S, T, but composed of horizontal and vertical line segments only) were presented, plus one of the two possible target letters H or U (also digital-clock-symbol like). The positions of the targets and of the remaining letters varied randomly. Digital-clock-symbol letters were used to discourage any strategy to search for a shape singleton in the no-singleton trials—that is, the letters were composed of the same horizontal and vertical line

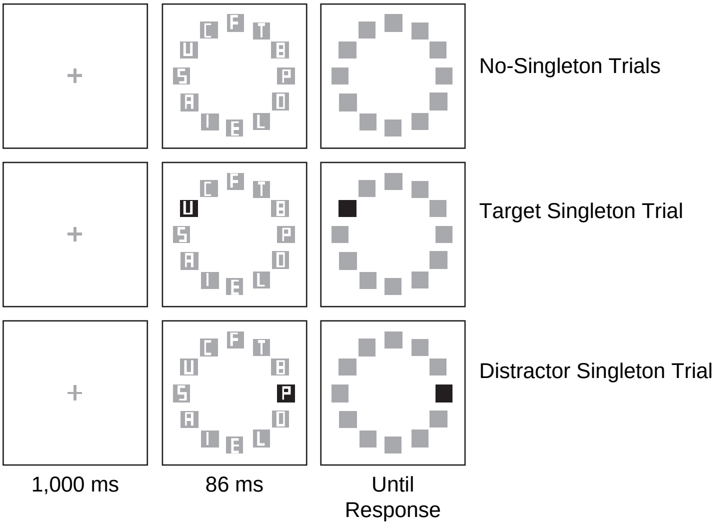

Figure 1. Displays presented in no-singleton trials (upper row), and target singleton trials (middle row), or distractor singleton trials (lower row) in Experiment 1. Time runs from left to right. (Note: the figure is not drawn to scale.)

segments, such that target letters and nontarget letters did not differ by a single shape feature. (A voluntary search for shape singletons has been made responsible for apparently unintended shifts of attention to colour singletons by Bacon & Egeth, 1994.) The third display was the same as the second, except that no letters were presented.

In the no-singleton trials, all squares were green. In the singleton trials, 11 squares were green, and 1 randomly chosen square was red. Depending on the condition, the position of the red square (i.e., position of the colour singleton) was either always the same as the target's position (target singleton) or never the same as the target's position (distractor singleton).

Procedure. The fixation cross was presented for 1000 ms, and replaced by the search display, consisting of the squares and the letters. The letters disappeared after 86 ms. The squares were displayed without the letters until a response was registered. Errors were immediately followed by auditory error feedback (a 100 ms tone). The intertrial interval was 1100 ms.

The participant's task was to indicate the identity of the target (H or U) with a key press (left or right). The instructions emphasized accuracy of the responses; speed was explained to be of only minor importance. The participants were instructed to keep their eyes fixated on the screen's centre (marked by the fixation cross) throughout the trial, and doing so was explained to be the best strategy to detect as many targets as possible. They worked on 16 no-singleton trials in order to check whether they had understood the task. The participants were fully informed about what to expect in the experiment.

The experiment comprised eight blocks. They were all-singleton blocks and rare-singleton blocks. Each all-singleton block comprised 20 singleton trials, in which H and U appeared equally often in random order. Rare-singleton blocks were much longer than all-singleton blocks. Each rare-singleton block consisted of eight repetitions of 25-trial units that were composed of 24 no-singleton trials (half with H and half with U as the target, respectively) and 1 singleton trial. The 24 no-singleton trials and the singleton trial were presented in a random order to ensure that the singleton trial could occur at any serial position within each 25-trial sequence. Within each rare-singleton block, H and U were used equally often as the targets in the singleton trials following a prespecified pseudorandom sequence. Each block was preceded by five warm-up trials that were not analysed. In the case of the all-singleton blocks, the warm-up trials were of the same type as the following experimental trials. In the case of the rare-singleton blocks, the warm-up trials were no-singleton trials.

Each block started with a short written instruction that appeared on the computer screen. The instruction informed about the frequency and about the usefulness of the singleton (i.e., whether its position coincided with that of the target or a distractor) in the following block. For example, the instruction for a block with frequent target singletons was: “In the next block, there will be a differently coloured square in each trial. You should ignore that square because the square is never at the position of the target.” In a similar way, the instruction for a block with rare target singletons was: “In the next block, there will be a differently coloured square in one out of 25 trials. You should use the square to find the target because the differently coloured square is always at the same position as the target”.

All-singleton blocks and rare-singleton blocks alternated, with blocks 1, 3, 5, and 7 being all all-singleton blocks, and blocks 2, 4, 6, and 8, being all rare-singleton blocks. Half of the participants received the all-singleton blocks with target singletons in blocks 1 and 3, and with distractor singletons in blocks 5 and 7; for the other half, the order was reversed. The variable singleton-target position relation, henceforth called position relation (i.e., whether the singleton was a target singleton or a distractor singleton) in the rare-singleton blocks was completely crossed with position relation in the preceding all-singleton blocks, because we wanted to control for possible carry over effects from the all-singleton blocks to the rare-singleton blocks. Accordingly, one of the blocks 2 and 4, and one of the blocks 6 and 8, was a rare-singleton block with target singletons and one was a rare-singleton block with distractor singletons. Apart from this combinatorial restriction, all possible orders of rare-singleton blocks with target singletons and distractor singletons were used and their frequency was balanced across participants.

Results

The proportion of correct answers was computed for each all-singleton block, for the singleton trials of each rare-singleton block, and for the no-singleton trials of each rare-singleton block (note that this yields two measures for no-singleton trials, one from rare-target-singleton blocks, and one from the rare-distractor-singleton blocks). Figure 2 shows the results as a function of whether the singleton was presented at the position of the target or a distractor within the respective block.

A first analysis concerned the rare-singleton blocks only. A 2 (display type: Singleton vs. no-singleton display) × 2 (block: Target vs. distractor singleton) × 2 (position relation in the preceding all-singleton block: Target singleton vs. distractor singleton) analysis of variance (ANOVA) revealed a significant main effect for block, $F(1, 7) = 23.95$, $p < .01$, and display type, $F(1, 7) = 6.99$, $p < .05$. The main effect of position relation in the preceding block was not significant, $F(1, 7) = 2.4$, $p > .10$. The main effects of block and display type interacted, $F(1, 7) = 26.93$, $p < .001$. There were no other significant interactions, all Fs < 1. Subsequent t-tests were conducted to test

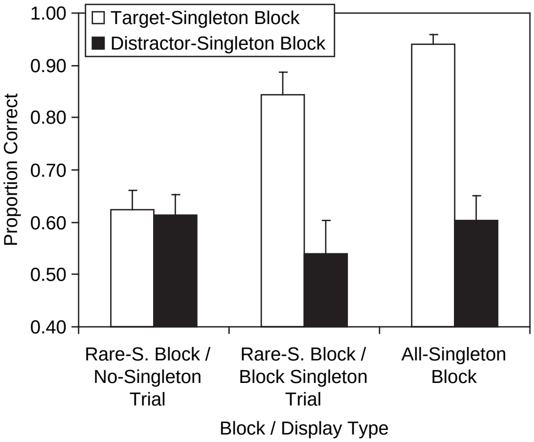

Figure 2. Mean proportion of correct answers for no-singleton and singleton trials from the rare-singleton blocks, as well as for the singleton trials of the all-singleton blocks in Experiment 1. Singleton-target position relation (target singleton or distractor singleton) was varied between blocks. Rare-S Block stands for rare-singleton block. Error bars represent standard errors of the mean.

whether the Block × Display type interaction reflected better performance with rare target singletons as compared to no-singleton displays of the same block, worse performance with distractor singletons as compared to no-singleton displays, or both. In the blocks with target singletons, performance was significantly better for singleton displays than for no-singleton displays, $t(7) = 7.56$, $p < .001$. There was a small but nonsignifiacant trend towards worse performance with distractor singletons as would be predicted by the hypothesis that a singleton tends to draw attention to itself, irrespective of an intention, $t(7) = 1.65$, $p = .08$ (one-tailed).

An additional test concerned performance with rare versus frequent target and distractor singletons. A 2 (position relation: Target singleton vs. distractor singleton) × 2 (singleton frequency: Rare vs. frequent) ANOVA revealed a significant main effect of position relation, $F(1,\ 7) = 72.25$, $p < .001$, reflecting a performance benefit (ΔP) for displays with a target singleton of $\Delta P = .32$ proportion correct, and a main effect of frequency just failing to reach significance, $F(1,\ 7) = 5.1$, $p = .06$, reflecting a performance benefit for frequent singletons over rare singletons of $\Delta P = .08$ proportion correct. The interaction term was not significant, $F < 1$.

Discussion

Several substantial results were obtained. First, as indicated by the significant benefit from the target singleton over the no-singleton trials of the same block, rare singletons were quickly attended to. Second, as indicated by the absence of a pronounced cost for a rare distractor singleton (see also below), attentional shifts depended almost exclusively on the attentional settings of the observer that allowed participants to ignore the singleton if it was known to be presented at the position of the distractor. Third, a comparison between frequent and rare singletons revealed a tendency towards a general performance decrement (i.e., a cost) in rare-singleton trials that was roughly equal for target and distractor singletons. This effect is important to appropriately understand the small costs produced by distractor singletons relative to no-singleton trials, because the effect indicates that these costs are not incurred by the spatial distance between the target and the distractor singleton. Instead, this effect may reflect some kind of nonspatial cost (cf. Folk & Remington, 1998) that is incurred in the rare-singleton blocks. Spatial costs from an involuntary orienting of attention, in contrast, should have registered with the target being presented away from the singleton (in the distractor singleton condition) but not or less so with the target being presented at the singleton position (in the target singleton condition).

Fourth, there were no significant carryover effects from the all-singleton blocks (with target or distractor singletons) to the rare-singleton blocks, indicating that participants adopted a new attentional top-down setting, depending on the instructions given before each new block.

The current results are in agreement with the hypothesis that top-down contingent capture is also possible with rare singletons. This implies that attentional control settings can be maintained over a long duration despite their not being applicable to the vast majority of the trials. Moreover, the effect of position relation was as high with rare as with frequent singletons. This result indicates that adopting and maintaining a control setting is hardly demanding. This is because the average utility of adopting a control setting for an application in every trial is very different from the average utility for an application in only 4% of the trials. That the effect of singleton position was that high indicates that costs were not a factor of major importance for the adoption of an attentional set for colour.

EXPERIMENT 2a

Experiment 2a varied the SOA between the singleton and the target letters in addition to the position of the singleton. Three SOAs were used, with durations of 0, 200, and 400 ms. SOA was varied with the aim to unveil the time course of costs and benefits with rare singletons. For target singletons, attentional control settings should be specified in advance of the display, so that attention could be shifted quickly to the position of a target singleton, for example, enabling the identification of the target letter at that position even with a short SOA (e.g., 0 ms) (cf. Ansorge, Horstmann, & Carbone, 2005). Moreover, if anything, attention should be kept at the target singleton's position until the target is presented, which might further improve performance with a longer SOA. Thus, it was assumed that most of the benefit with the presentation of rare singletons can already be registered with a 0 ms SOA. If additional benefits accrue with an SOA of 200 ms, this would indicate that the slower tail of the latency distribution of attentional shifts is too slow for the 0 ms SOA. For distractor singletons, no attentional control setting with regard to the singleton should be established, and the distractor singletons should be simply ignored; thus, no benefits or costs are expected.

With a variation of the SOA, it is additionally possible to test a variant of the hypothesis that a singleton captures attention independently of a corresponding attentional setting with a singleton distractor. According to the bottom-up singleton-capture view, a singleton distractor initially captures attention involuntarily and quickly, but intentional control over attention is regained with some delay, enabling the reorienting of attention in the eventuality that the singleton is known to be nonpredictive (e.g., Kim & Cave, 1999; Posner & Cohen, 1984; Theeuwes, Atchley, & Kramer, 2000). Therefore, if a rare singleton elicits stimulus-driven singleton capture, SOA should not affect performance with a target singleton because there is no need to reorient attention, but SOA should affect performance with a distractor singleton, producing costs at shorter SOAs, which should be eliminated at longer SOAs when attention has been reoriented to the centre of the screen. Previous research indicated that at least an SOA of 400 ms is long enough to allow for a reorienting of attention (cf. Ansorge & Heumann, 2004; Posner & Cohen, 1984; for a review see Taylor & Klein, 1998).

Method

Participants. Eighteen participants from the same pool participated in partial fulfilment of study requirements or for payment.

Apparatus and stimuli. These were the same as in Experiment 1.

Procedure. Each trial comprised four displays. The first display was the 1000 ms presentation of the fixation cross. It was followed by the 12 coloured squares presented without the letters, which were displayed for 0 ms, 200 ms, or 400 ms. The letters were then displayed for 86 ms. The last display contained only the squares but not the letters (as in the second display) and lasted until a response was made. Error feedback was given as in Experiment 1. The task was the same as in Experiment 1.

Position of the singleton relative to that of the target was a blocked variable: For half of the participants, target singletons were presented in the first half of the experiment, and distractor singletons were presented in the second. This order was reversed for the remaining participants. Each experimental half comprised two sections. Every section was preceded by a written instruction on the computer display indicating the frequency of the singleton and whether it was presented at the position of the target or of a distractor. Before the experiment proper was started, each participant received 18 no-singleton trials in order to provide some practice and to check for an understanding of the task.

The first half of the experiment began with three 20-trial all-singleton blocks, one block for each SOA. The second section of the first half comprised 375 experimental trials of rare-singleton blocks, 125 for each SOA. These 375 experimental trials were administered in 15 repetitions of 25-trial units, each comprising 24 no-singleton displays and 1 singleton display. The sequential position of the singleton display within the 25-trial units was random. Each 25-trial unit was preceded by five warm-up trials with no-singleton displays. After each unit, participants were given the opportunity for a short rest. Within each unit, the same SOA was used. SOA was also the same in every third unit, with serial position in the sequence being balanced.

The second half of the experiment had the same structure as the one described, with three all-singleton blocks (consisting of only singleton displays), followed by fifteen 25-trial units. If in the first half, target singletons were presented, in the second half, distractor singletons were presented, or vice versa. The two possible orders of the two different position relation blocks (target singletons first, distractor singletons second, or the reversed order) were balanced across participants.

Results

The proportion of correct answers was computed in the same way as in Experiment 1. Figure 3 displays the results. Similar to the first experiment, an initial analysis was conducted using the rare-singleton blocks only. An ANOVA with the variables SOA (0, 200, 400 ms), display type (singleton vs. no-singleton display), and position relation (target vs. distractor) revealed a significant main effect of display type, $F(1, 17) = 32.1$, $p < .001$, and position relation, $F(1, 17) = 41.8$, $p < .001$, and SOA, $F(2, 34) = 3.7$, $p < .05$, as well

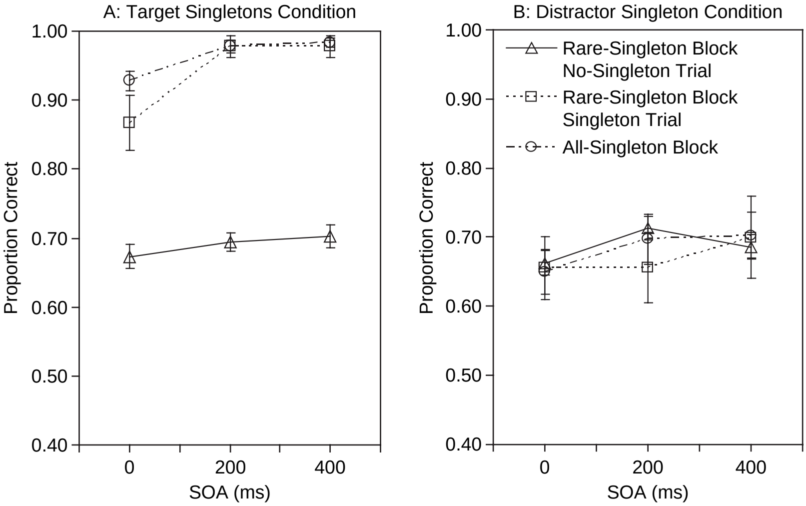

Figure 3. Mean proportion of correct answers at SOAs of 0, 200, and 400 ms in Experiment 2a. The left and the right graphs show the results for the target and the distractor singleton conditions, respectively.

as a significant Display type × Position relation interaction, $F(1, 17) = 31.1$, $p < .001$. The remaining interactions were not significant, Fs < 2.0.

The Display type × Position relation interaction reflects better performance in singleton than in no-singleton trials in target singleton blocks (.94 vs. .69), $t(17) = 11.5$, $p < .001$, whereas in the distractor singleton blocks, performance was similar in singleton and no-singleton trials (.67 vs. .69), $t(17) < 1$. The main effect for SOA reflects somewhat worse performance with a 0 ms SOA (.72) than with SOAs of 200 ms (.76) and 400 ms (.77).

A second analysis tested the effects of rareness. The ANOVA with the variables SOA (0, 200, 400 ms), singleton frequency (frequent singletons vs. rare singletons), and position relation (target singleton vs. distractor singleton) revealed a significant main effect of position relation, $F(1, 17) = 83.3$, $p < .001$, and of SOA, $F(2, 34) = 4.6$, $p < .05$, whereas the other main effect and the interactions were not significant, all Fs < 1.2.

Performance was better with target singletons (.95) than with distractor singletons (.68), and performance was better with positive SOAs (.83. and .84, for the SOAs of 200 ms and 400 ms, respectively) than with simultaneous presentation (.78).

Discussion

The results are similar to those in Experiment 1, in that there was a large benefit with the target singletons relative to the no-singleton displays of the same block, but not a proportional cost with the distractor singletons. This finding is compatible with the hypothesis that an attentional control setting for the colour feature or for the singleton status of a stimulus was established, and maintained even during the no-singleton trials. Performance was influenced by SOA, suggesting that the slower part of the latency distribution registers in accuracy benefits only with the longer SOAs. Singleton frequency had only a small effect on performance, indicating that the attentional setting can be easily maintained without much loss in efficiency.

It is important to note that SOA did not interact with the singleton target position relation, but that the effect of SOA was additive to the other variables. This pattern is at odds with a stimulus-driven singleton-capture account for the present results, which would have predicted costs at short SOAs but none or less cost at long SOAs for distractor singletons, due to a fast reflexive shifting of attention to the distractor singleton, followed by a reallocation of attention to the centre of the screen shortly thereafter (e.g., Kim & Cave, 1999; Theeuwes et al., 2000).

EXPERIMENT 2b

Experiment 2b used essentially the same procedure as Experiment 2a, but with a refined range of SOAs (0, 50, and 100 ms). The reason for this variation was that it might be argued that the sequence of (a) the allocation of attention to the distractor singleton and (b) the reallocation to the screen's centre may take place at shorter SOAs than tested in Experiment 2a. Moreover, bottom-up singleton capture could be evident only in conditions where the stimulus-driven capture effect is given enough time to build up (cf. Ansorge et al., 2005). In fact, Theeuwes et al. (2000) observed stimulus-driven singleton capture with a small but positive SOA between the singleton and the target. That is, the 0 ms SOA might have been too short to reveal clear-cut evidence for costs from a stimulus-driven shift to the distractor singleton.

Method

Participants. Eighteen adults from the same participants' pool participated in partial fulfilment of study requirements or for payment.

Apparatus, stimuli, and procedure. These were the same as in Experiment 2a, except for the changed SOAs.

Results

The proportion of correct answers was computed in the same way as before. The main results are given in Figure 4. The first analysis used the rare-singleton blocks only. An ANOVA with the variables SOA (0, 50, 100 ms), display type (singleton vs. no-singleton display), and singleton-target position relation (target singleton vs. distractor singleton) revealed a significant main effect for display type, $F(1, 17) = 7.0$, $p < .05$, a significant main effect for position relation, $F(1, 17) = 38.2$, $p < .001$, and a significant Display type × Position relation interaction, $F(2, 34) = 30.4$, $p < .001$. The Display type × Position relation interaction indicates that within rare-singleton blocks with target singletons, performance was better in singleton than in the no-singleton trials (.88 vs. .72), $t(17) = 5.7$, $p < .001$, whereas in rare-singleton blocks with distractor singletons, performance was worse in the singleton than in the no-singleton trials (.66 vs. .72), $t(17) = 2.3$, $p < .05$.

The main effect for SOA did not reach significance ($F < 1$), but there was a marginally significant interaction between display type and SOA, $F(2, 34) = 2.7$, $p = .08$, reflecting that in singleton displays, performance with a 0 ms SOA was slightly better than performance with the positive SOAs (see Figure 4), whereas no such effect was present in the no-singleton displays.

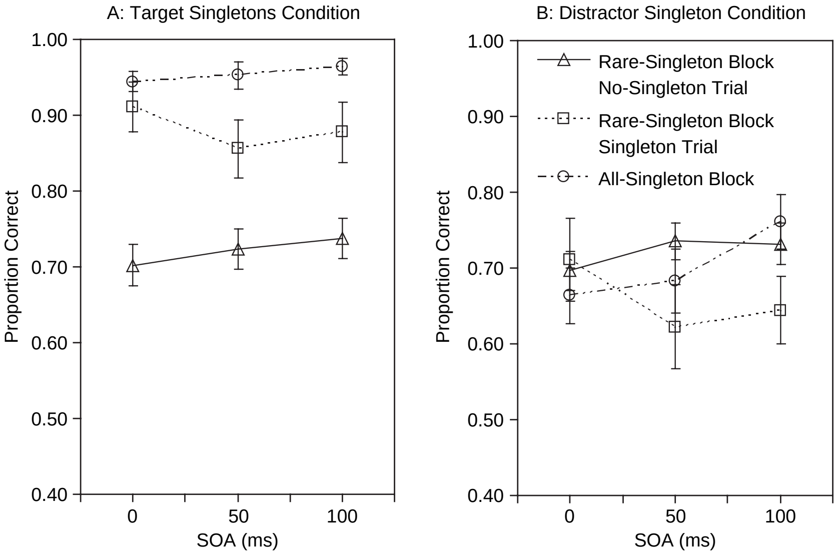

Figure 4. Mean proportion of correct answers at SOAs of 0, 50, and 100 ms in Experiment 2a. The left and the right graphs show the results for the target and the distractor singleton conditions, respectively.

Importantly, the three-way interaction was not significant ($F < 1$), revealing no evidence for the result pattern assumed under the bottom-up singleton capture hypothesis.

A second analysis tested the effects of rareness. The ANOVA with the variables SOA (0, 50, 100 ms), frequency (frequent vs. rare singletons), and position relation (target vs. distractor) revealed a significant main effect of position relation, $F(1,\ 17) = 86.7$, $p < .001$, reflecting better performance with target than with distractor singletons (.92 vs. .68), and a significant main effect for frequency, $F(1,\ 17) = 9.5$, $p < .01$, reflecting better performance with frequent than with rare singletons (.83 vs. .77). The main effect for SOA was not significant, $F(2,\ 34) = 1.3$. There was a marginally significant interaction between SOA and singleton frequency, $F(2,\ 24) = 2.7$, $p = .08$, reflecting that in rare singleton blocks, performance with a 0 ms SOA was slightly better than performance with the positive SOAs (see Figure 4), whereas no such effect was present in the all-singleton blocks. The other interactions were not significant (Fs < 1), indicating no evidence supporting a bottom-up singleton-capture account of the present results.

In order to clarify the marginally significant SOA × Singleton frequency interaction, separate Frequency (frequent vs. rare singletons) × Position relation (target singleton vs. distractor singleton) ANOVAS for each SOA were conducted, revealing significant main effects for position relation, *F*s > 38.0, *p*s < .001, reflecting the superior performance with the target singletons, and a significant main effect for frequency with the 50 ms SOA, $F(1, 17) = 5.5$, $p < .05$, and the 100 ms SOA, $F(1, 17) = 7.7$, $p < .05$, not for the 0 ms SOA, $F < 1$. There were no significant Position relation × Block interactions, *F*s < 1.1.

Discussion

Experiment 2b replicated the basic results from Experiment 1 with a large benefit for the target singleton at a 0 ms SOA as compared to the no-singleton trials, indicating a quick shift of attention to the letter at the singleton's position. Furthermore, the results did not support the predictions derived from the bottom-up singleton capture account. We reasoned that according to this account, initial bottom-up singleton capture should deteriorate performance at short SOAs with a distractor singleton, whereas a corresponding performance cost should be absent with a target singleton. While we indeed found evidence for costs at SOAs of 50 ms and 100 ms with distractor singletons, the same costs were present with target singletons (which we discuss in the General Discussion). Thus, the overall pattern of results does not reveal bottom-up singleton capture in the present task. Note that this is not to imply that unintended capture by nominally irrelevant singletons can never occur, which would be contradicted by results from other experiments (e.g., Theeuwes, 1992, 1994). Rather, the results thus far show that a quick attentional response to rare singletons is not easily explained by bottom-up singleton capture. Bottom-up singleton capture, in turn, may depend on factors in addition to the mere presence of a singleton, for example, task demands that foster occasional intrusions of task-inappropriate singleton-search strategies (for general arguments along these lines see Kane & Engle, 2003).

EXPERIMENT 3

Experiment 3 is a control experiment to answer the following question: Is the present task insensitive to costs incurred by singletons that are presented at a distance from the targets? If so, then the present paradigm may not be able to test the possible presence of bottom-up singleton-capture. Yet, in the previous experiments, costs by distractor singletons were used to test for the singleton-capture account of the influence of the rare singletons. One motivation for conducting Experiment 3 was to test whether particular aspects of our procedure could have prevented costs by distractor singletons in general.

In Experiments 1 and 2, we demonstrated that target singletons allowed for benefits, whereas distractor singletons did not produce proportional costs, and we attributed these results to top-down contingent capture by colour or by the singleton. Fortunately, even a contingent-capture account predicts costs by a distractor singleton, given that it matches the control settings. For instance, provided that attending to a singleton is a useful strategy (i.e., that it helps to locate the target in a majority of the trials) such that participants adopt a corresponding attentional control setting, a distractor singleton presented within the same block is expected to match a control setting and, thus, to produce costs. To test this prediction, rare singletons, which were presented either at target location or at distance from the target, were unpredictably intermixed within blocks, such that target and distractor singletons were to be processed by means of the same attentional setting. Participants were instructed to attend to the singletons. It is important to note that attending to the singletons paid, because—on the average—singletons were predictive: The probability of the singleton-target coincidence (.50) was considerably higher than a mere chance probability of a coincidence on just 1/*d* of the trails (where *d* would have been display size, cf. Yantis & Egeth, 1999). If participants form a control setting to attend to the rare singletons under these conditions, the contingent-capture account predicts both benefits for valid or target singletons and costs for invalid or distractor singletons.

Method

Participants. Twelve students or visitors at Bielefeld University participated in partial fulfilment of study requirements or for payment.

Apparatus and stimuli. These were the same as before.

Procedure. The experiment comprised two practice blocks and one experimental block. The first practice block consisted of 16 trials with no-singleton displays. In the second practice block, also comprising 16 trials, a target singleton was presented in each trial. This practice with the target singletons was intended to facilitate the formation of an attentional setting for the singleton.

There were a total of 500 experimental trials, which were presented within four blocks, with the opportunity to rest after every 125 experimental trials. Each block began with five no-singleton warm-up trials. The experimental trials were composed of 20 repetitions of units containing 24 no-singleton trials plus one singleton trial. In the 24 no-singleton trials of each unit, the target's position varied randomly, with half of the trials containing an H and the other half of the trials containing a U as a target. The spatial position of the singleton in a given trial and the sequential position of the singleton trial in a given 25-trial unit also varied randomly. The singleton was at the target position in half of the 25-trial units and at a distractor position in the remaining units. Thus, singleton and target positions coincided with an above-chance probability and singletons were predictive of the position of the target on the average. Two pseudorandom orders for valid or target singletons and invalid or distractor singletons were used, balanced across participants. Half of the participants within each pseudorandom order assignment received green as the no-singleton display colour and red as the singleton colour, whereas for the other half of the participants the colour assignment was reversed. (Colour was not varied in the previous experiments to prevent too large numbers of to-be-orthogonally varied between-participants variables.)

The participants were fully informed about the frequency of the singleton and about the fact that the singleton was at the target's position in half of the singleton trials, but at the distractor's position in the other half of the singleton trials. As in the preceding experiments, they were instructed to fixate their eyes on the fixation cross throughout the trial in order to detect as many targets as possible. Participants were further instructed to attend to the singleton if it appeared because this would help to find the target in half of the trials, which would be a beneficial strategy on the average.

Results

The proportion of correct answers was computed as before. Figure 5 shows the results. The accuracy data were analysed by means of an ANOVA, with

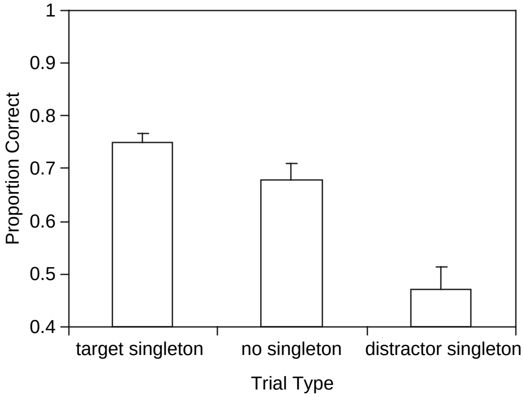

Figure 5. Mean proportion of correct answers in Experiment 3.

trial type (target singleton vs. no-singleton vs. distractor singleton trial). Trial type significantly affected performance, $F(2, 22) = 49.1$, $p < .001$. Colour assignment (i.e., whether the singleton was red or green) did not produce any significant effects when included in the ANOVA, all Fs < 2.2 (type of trial affected performance somewhat more with a green singleton among red nonsingletons). Planned comparisons revealed that the performance in the no-singleton trials was worse than the performance in target singleton trials, $t(11) = 2.7$, $p < .05$, and better than performance in distractor singleton trials, $t(11) = 7.4$, $p < .001$. An inspection of the performance data in the singleton trials on a trial-by-trial basis revealed a stable data pattern across the repetitions of the singleton trials without any linear trend that would have indicated a change of the attentional control settings (the search strategy) in the course of the rare-singleton blocks.

Discussion

Under conditions of the same overall average predictive value of the singletons, we obtained performance benefits with rare target singletons, as well as performance costs with distractor singletons in the very same blocks. Thus, if singletons are predictive of the target's position on the average, both target and distractor singletons were attended to. While benefits have been observed with rare target singletons in the preceding experiments as well, the costs that were incurred selectively by the rare distractor singletons of the present experiment had often been weak in the preceding experiments, and, more importantly, the costs by the rare singletons in the previous experiments were nonspatial in that they were not specific to the distractor singleton conditions but were also observed with the target singletons. The present experiment's pattern of results was predicted by the contingent-capture account of the visuospatial attentional effect of the rare singletons. In the preceding experiments, selective costs for distractor singletons have been weak because the participants always knew that these singletons would be of no help in finding the targets. Accordingly, the participants did not set the attentional control settings to search for and to attend to the distractor singletons. In contrast, in the present experiment, each upcoming singleton could have been at the position of the target. Furthermore, it paid to attend to the singletons and participants were instructed to do so. Therefore, participants would have had a reason to willingly attend to each of the singletons. The data are consistent with this reasoning. Furthermore, as would have been expected, although an incentive to attend to the singleton was provided in the present experiment, it was apparently weaker than with a target singleton in the preceding experiments; the benefit with a target singleton in the present experiment (predictive of the target in 50% of the singleton trials) was not as high as with a target singleton in the Experiments 1 and 2 (predictive of the target in 100% of the singleton trials). Correspondingly, the costs in distractor singleton trials were higher than the costs with a distractor singleton in Experiments 1 and 2, in which there was a strong incentive not to attend to the distractor singleton.

EXPERIMENT 4

From a pragmatic perspective, presenting rare singletons in only 4% of the trials is rather uneconomical because most of the data gathered pertain to the relatively uninteresting no-singleton conditions. Thus, it was of interest whether presenting the rare singleton displays more often would alter the results, thereby, bridging Experiments 1–3 and Experiment 5 (as well as future experiments with rare singletons), where somewhat higher singleton frequencies were used. Two levels of singleton rareness were tested in Experiment 4, with a singleton trial among 24 (as before) or among 12 no-singleton display trials. Experiment 4a used target singletons at these two levels of rareness, whereas Experiment 4b used distractor singletons at these two levels of rareness.

Method: Experiment 4a

Participants. 12 participants were recruited and gratified as before.

Apparatus and stimuli. These were the same as in Experiment 1.

Procedure. The experiment comprised five experimental blocks and one practice block. The practice block consisted of 16 trials of the letter search task without a singleton. It was followed by an all-singleton block with target singletons which comprised 60 trials (in which the two targets appeared equally often), preceded by five warm-up trials. The remainder of the experiment comprised four rare-singleton blocks with target singletons, with the two relative frequencies presented in alternating blocks. In the 1/13 frequency blocks, there was one singleton trial per 12 no-singleton trials, whereas in the 1/25 frequency blocks, there was one singleton trial per 24 no-singleton trials. Each of the two 1/13 frequency blocks consisted of ten repetitions of 13-trial units, with the 12 nonsingleton displays and the one singleton display within each unit presented in a random order. The 10 units were presented without pauses. The two targets appeared equally often within the sequence of no-singleton trials of each unit, and they appeared equally often averaged across the singleton trials of the two blocks. Each of the two 1/25 frequency blocks consisted of five repetitions of the 25-trial units, with each unit consisting of 24 no-singleton displays and 1 singleton display. The two targets appeared equally often within the sequence of no-singleton-display trials of each unit, and they appeared equally often averaged across the singleton-display trials of the two blocks. Each block started with an instruction displayed on the computer screen that informed the participants about the frequencies of the singleton trials which was followed by five no-singleton display warm-up trials. Half of the participants received a 1/13 frequency block first, whereas the other half of the participants received a 1/25 frequency block first. In total, there were 20 singletons trials from the 1/13 frequency block, and 10 singleton trials from the 1/25 frequency blocks.

Method: Experiment 4b

Participants. Eight participants were recruited as before.

Apparatus, stimuli, and procedure. These were the same as in Experiment 4a, except as noted. All singletons were presented at a randomly chosen distractor location. Instructions were changed accordingly.

Results

Experiment 4a. The proportion of correct answers was computed for the no-singleton displays of each rare-singleton block, the singleton displays of each rare-singleton block, and the singleton displays of the all-singleton block. The left-hand graph in Figure 6 shows the results for the rare-singleton blocks. Proportion correct with target singletons in the all-singleton block was .91 (indicated in the figure by a dotted line).

A first analysis concerned the rare-singleton blocks only. A 2 (display type: Singleton vs. no-singleton trial) × 2 (singleton frequency: 1/13 vs. 1/25) ANOVA revealed a significant main effect of display type only, $F(1, 11) = 92.4$, $p < .001$, while the other effects were not significant, all $F\text{s} < 1$. There was a reliable .26 performance benefit in proportion correct for the singleton displays over the no-singleton displays, while no benefits or costs occurred depending on whether the singleton appeared with a relative frequency of 8% or 4%.

A one-way ANOVA including the singleton trials of the all-singleton blocks with the factor singleton frequency (100% vs. 8% vs. 4%) also did not reveal a significant main effect or an interaction of singleton frequency, all $F\text{s}(1, 11) < 1$.

Experiment 4b. The proportion of correct answers was computed as before. The right-hand graph in Figure 6 shows the results for the rare-singletons blocks. Proportion correct in the all-singleton block with distractor singletons was .68 (indicated in the figure by a dotted line).

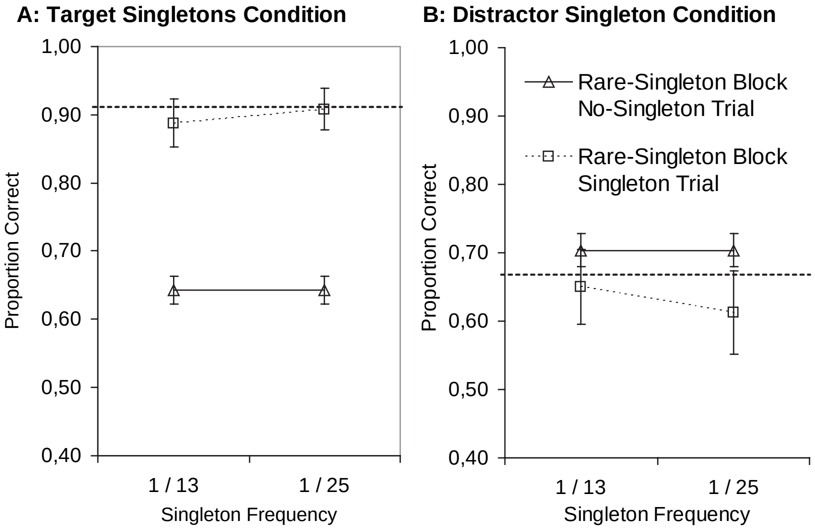

Figure 6. Mean proportion of correct answers in singleton and no-singleton trials of Experiment 4, separately for blocks with 12 and 24 no-singleton displays per singleton display, respectively. The left and the right graphs show the results for the target and the distractor singleton conditions, respectively. The dotted lines indicate the performance in the corresponding all-singleton blocks.

A first analysis concerned the rare-singleton blocks only. A 2 (display type: Singleton vs. no-singleton) × 2 (singleton frequency: 1/13 vs. 1/25) ANOVA revealed no significant effects, all Fs(1, 7) < 1.7. Likewise, a one-way ANOVA with the distractor singletons of the all-singleton block and the two rare-singleton conditions revealed no significant main effect of singleton frequency, $F(1, 7) < 1.1$, as well.

Discussion

The experiment replicated the main finding indicating top-down contingent attentional capture by the rare singleton at a 0 ms SOA: Benefits by target singletons but little costs by distractor singletons. There was also virtually no effect for the singleton frequency: Whether the singleton was presented in each trial, in 8%, or in 4% of the trials did not significantly affect performance. One could speculate whether the null effect for singleton frequency in the present experiment is a matter of statistical power; indeed, eyeballing at Figure 6 indicates a small performance decrement at least with distractor singletons. Possibly, this difference would reach significance if more participants were run. However, even if taken for granted that costs could be statistically detected with more participants, the important result is that the overall pattern of results is relatively unaffected by presenting the singletons with a high or low level of rareness.

EXPERIMENT 5

Thus far, accuracy was used as the dependent measure. However, most previous studies used RTs to pinpoint visuospatial attention capture effects. Thus, it is conceivable that more evidence for stimulus-driven capture is obtained with RTs as a dependent measure (e.g., Theeuwes, 1992, 1994; but see Yantis & Egeth, 1999). Therefore, in Experiment 5 we tested responses to rare singletons at the target's or at the distractor's position with an alternative measure: RTs to targets in search displays of varying set sizes. Participants searched through 4, 8, or 12 letters, which were uniformly coloured in eight out of nine trials, and contained a colour singleton in one out of nine trials. Set size (i.e., number of letters) was varied to test search efficiency. In the no-singleton displays we expected search to be nonefficient with RT increasing as a function of the number of stimuli in the display, because participants had to search for a spatial configuration of vertical and horizontal line features to find the target among the nontarget stimuli (cf. Treisman & Gelade, 1980). (Note that the expected RT set size effect in the no-singleton trials would corroborate our assumption put forward at the outset of the current study.) However, in the target singleton displays, no set size effect is expected. According to the contingent-capture hypothesis, attention would be shifted quickly to the target, whose position is marked by the colour singleton. Therefore, the target would always be the first letter attended to, and search times would be unaffected by the total number of letters presented. Therefore, we expected an interaction between the variables set size and presence of the target singleton. Also, predictions for the distractor singleton condition were basically the same for singleton and no-singleton displays. Because the singleton is of no use to identify the position of the target, search would be nonefficient in both distractor singleton and no-singleton displays.

Method

Participants. Twelve students or visitors at Bielefeld University participated in the experiment. They were paid €6 per hour.

Apparatus, stimuli, and procedure. The experiment comprised two parts, one with target singletons and one with distractor singletons (serial position was balanced across participants). Within each part, three sections presented frequent and rare singletons blocked for set size (serial positions of set sizes within the experiment were balanced across participants). The stimuli in the set size 12 condition corresponded to that in the previous experiments. In the set size 8 and set size 4 conditions, stimuli were presented in equally spaced positions on an imaginary circle of 2.2° and 1.3° radius, respectively, always beginning with the 0° position. Eccentricity was varied to hold approximately constant stimulus density. Wolfe, O'Neill, and Bennett (1998) found eccentricity to have no or only little effect if all items within a trial are presented at the same eccentricity. Density, a factor which we controlled for, on the other hand, has been found to influence pop-out (Nothdurft, 2000).

In each section, a first (all-singleton) block of 10 training and 30 experimental trials presented a singleton in each trial. The second (rare-singleton) block comprised 10 repetitions of units with 8 no-singleton trials and 1 singleton trial. The rare-singleton block was preceded by 10 warm-up trials without a singleton.

Participants were instructed to respond quickly while retaining a high level of accuracy. Other details corresponded to that of the preceding experiments.

Results and discussion

RTs faster than 200 ms and RTs slower than 2.500 ms (2%) were not analysed. Errors were excluded from the RT analyses (2%). Figure 7 shows the results for the target and the distractor singleton conditions.

An overall ANOVA of the RTs, with the variables position relation (target singleton or distractor singleton), display type (frequent singleton, rare

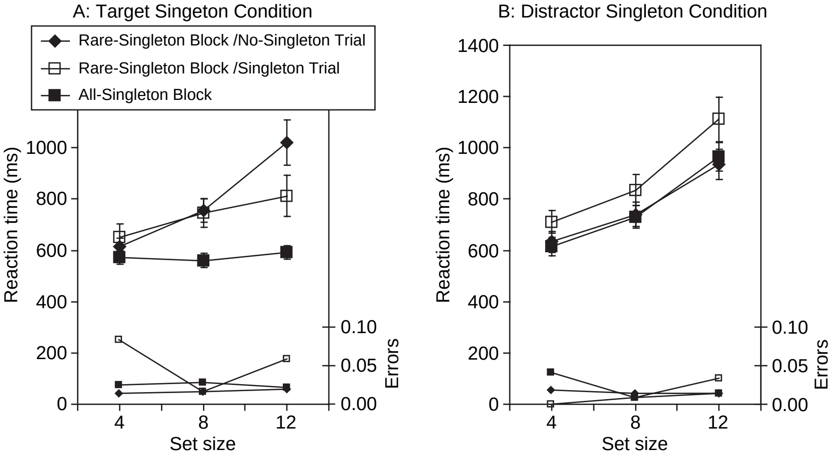

Figure 7. RT and error proportions in Experiment 5. The left and the right graphs show the results for the target and the distractor singleton conditions, respectively.

singleton, and no singleton), and set size (4 vs. 8 vs. 12) indicated that all main effects and interactions are significant, all $F\text{s} > 5.8$, all $p\text{s} < .01$.

A corresponding ANOVA of the error proportions revealed significant main effects for singleton position, $F(1, 11) = 12.1$, $p < .01$, indicating more errors with a target singleton (.03) than with a distractor singleton (.02), and display type, $F(2, 22) = 5.5$, $p < .05$, indicating more errors in the rare singleton trials (.03) than in the no singleton trials (.02) and in the frequent singleton trials (.02). A significant interaction between singleton position and display type indicated that disproportionably more errors occurred in the rare target singleton trials (see Figure 7). (There was also a significant three-way interaction, $F(4, 44) = 4.66$, $p < .05$, which we do not interpret.) Overall, the errors gave no clear indication of a speed–accuracy tradeoff with the RT results, which are detailed now.

One aim of the study was to test whether there are RT costs with rare singletons relative to the frequent singletons, and whether the effects of singleton rareness are the same for target and distractor singletons. To test this, an ANOVA with the factors position relation (target singleton or distractor singleton), singleton frequency (rare vs. frequent), and set size (4 vs. 8 vs. 12) was conducted. The ANOVA revealed significant main effects for all factors, all $F\text{s} < 29.0$, all $p\text{s} < .001$, and a significant Position relation × Set size interaction, $F(2, 22) = 43.5$, $p < .001$. The interactions involving rareness were not significant, all $F\text{s} < 1.8$, all $p\text{s} > .18$. The main effect for singleton rareness reflects a 128 ms RT advantage for the frequent singleton trials, and the absence of an interaction with singleton rareness indicates that the costs were approximately the same across set sizes and position relations. The Position relation × Set size interaction reveals a shallow search slope of 8 ms/letter with target singletons, but a steep search slope of 47 ms/letter with distractor singletons.

We also tested whether the different search sets had an effect in the no-singleton trials. A two-way ANOVA of the RTs, with the variables set size and position relation (in the corresponding block in which the no-singleton trials were displayed), revealed a significant main effect for set size only, $F(2, 22) = 53$, $p < .001$. The mean search slope in the no-singleton trials was 41 ms/item.

Is search with the aid of a rare target singleton more efficient than search without such an aid? A two-way ANOVA of the RTs from the rare-singleton blocks with the variables set size and singleton presence was used to answer this question. It revealed significant main effects for set size, $F(2, 22) = 20.6$, $p < .001$, and singleton presence, $F(1, 11) = 7.3$, $p < .05$, and a significant interaction between the two variables, $F(2, 22) = 20.6$, $p < .001$. The significant interaction reflects that search was inefficient in the no-singleton trials (with a search slope of 44 ms/letter) while it was relatively shallow in the rare target singleton trials (search slope: 14 ms/letter).

A corresponding ANOVA for the rare distractor singletons revealed a significant main effect for set size, $F(2, 22) = 40.8$, $p < .001$, and singleton presence, $F(1, 11) = 35.2$, $p < .001$, and a marginally significant interaction, $F(2, 22) = 3.9$, $p = .06$. The main effect of trial type reflected a 117 ms slowing with singletons on average, and the interaction indicates that the slope in distractor singleton trials was somewhat steeper than in the no-singleton trials (50 vs. 38 ms/item).

GENERAL DISCUSSION

We started with the question whether a rare target singleton can be used in a visual search task to find the target, and found the answer to be in the affirmative: In all experiments, there was a sizeable performance benefit with rare target singletons relative to the no-singleton trials. Second, we found this benefit to be present even with a 0 ms SOA, where performance could benefit only from very fast attentional shifts. The performance benefit with target singletons was also not strongly improved by increasing the singleton-target SOA, which is also evidence for a low latency of the shift. A fast shift of attention is consistent with a contingent-capture account, assuming that the attentional control system can be set to a selected feature "offline", such that attention is oriented to the singleton right at the beginning of the display and without any intervening decisional processes during the trial (cf. Ansorge et al., 2005). In summary, we conclude that the maintenance of an attentional control set over an extensive number of trials is both possible, and relatively less demanding.

Experiment 5 added two important results. First, using a set size variation to probe search efficiency, and RT as the dependent variable, search was found to be quite efficient with a rare target singleton, which is in line with the hypothesis that contingent capture is also possible for rare feature singletons. Second, Experiment 5 revealed that displays with rare singletons are not as quickly responded to as displays with frequent singletons. Importantly, costs of approximately the same magnitude are present both with target and distractor singletons. This reveals that the costs incurred by the rare singletons are nonspatial, and are thus not aptly explained by the orientation of spatial attention to the singleton. We will come back to the discussion of costs later.

We also explored a rival explanation to the contingent capture account for the present experiments: That a singleton always captures attention, independently of the control setting (Kim & Cave, 1999; Theeuwes, 1992, 1994; Theeuwes & Godijn, 2001, 2002). However, several aspects of the data argue against a stimulus-driven singleton-capture explanation of the present data pattern. First, there were only small costs associated with a rare distractor singleton at 0 ms SOAs in Experiments 1, 2, and 4. That evidence for costs in these experiments was not stronger could not be simply attributed to the insensitivity of the method used in these experiments, because Experiment 3 demonstrated that relatively large costs incur if observers are given an incentive to attend to the rare singletons. That is, in Experiment 3, where the invalid or distractor singletons matched the control settings for a current block, costs were obtained with a 0 ms SOA. Second, as already noted, costs were not specific to the distractor singletons. Instead, the comparison of the rare singletons with the frequent singletons revealed nonspecific (i.e., nonspatial) costs for both target and distractor singletons. Third, based on predictions of Kim and Cave (1999), and Theeuwes and Godijn (2001, 2002), and observations made by Theeuwes et al. (2000), it was tested whether performance with distractor singletons would be changed when different SOAs are tested. In particular, it might be the case that stimulus-driven attentional capture by the singleton is quickly followed by an intentional reorienting, and—alternatively or in addition—the stimulus-driven singleton capture may build up over time (and is present only with short positive SOAs). However, these predictions were not confirmed.

A possible reason for the lack of stimulus-driven singleton capture in the present experiments is that the letter search task required a "focused" serial search mode that might prevent stimulus-driven singleton capture (e.g., Theeuwes, 2004). For example, Theeuwes and Burger (1998) have discussed the hypothesis that stimulus-driven singleton capture is possible only where participants are in a diffuse search mode or where the target is itself a singleton (cf. Bacon & Egeth, 1994).

In some of the present experiments, frequent singletons led to a somewhat better performance than rare singletons. This effect was especially strong with RTs as the dependent variable, but also present (at least as a trend) in the accuracy values. As we have repeatedly emphasized, these relative costs are best conceived of as nonspatial costs, because they were present with a singleton at the target and at a distractor position, and were of about the same size. From the present experiments, it can hardly be concluded as to what these nonspatial costs are. One possibility that we exclude as the main variable is the "priming of pop-out". For example, Maljkovic and Nakayama (1994), using an inconsistent mapping where singleton and nonsingleton colours switched repeatedly within a block of trials, found RTs to a singleton target of a given colour to be a function of immediate preceding repetitions of the singleton target of that colour. That is, if red was the singleton colour in trial N, RTs were faster if red was the singleton colour in the preceding trial N−1, and even faster if red was the singleton colour in trial N−2, and so on. This effect was present over 5–8 trials. Thus, it would be possible that performance with target singletons is worse in rare-singleton than in all-singleton blocks, because only in the latter, but not in the former, benefit from the priming of pop-out would apply. However, this explanation falls short in explaining the longer RTs with rare distractor-singletons. In this condition, the target colour was the same in both the no-singleton and the singleton trials.

An explanation of the nonspatial costs has to consider that the costs are present—although weak and instable—also with a zero SOA, and becomes somewhat more pronounced with SOAs of 50 ms and 100 ms, and appear to disappear with a 200 ms SOA. This result suggests that the effect arises early in perceptual processing and is not (entirely) due to processes at response production. Another possibility is that the costs are due to a switching of the task set between preceding no-singleton trials $N-1$ and actual singleton trials N (cf. Rogers & Monsell, 1995). Note, that according to this account, participants would have used a task set in the distractor singleton trials to actively ignore the distractor singleton.

The results from Experiment 5 deviate from the data reported by Yantis and Egeth (1999), where it was found that neither a rare distractor singleton (presented in 20% of the trials), nor a frequent distractor colour singleton (presented in 80% of the trials) interfered with search for a vertical among slightly tilted lines. The result from our Experiment 4 suggests that the differences in singleton frequency—20% in their rare singleton condition and 4%, 8%, or 11%, in our experiments—is not crucial: Experiment 4 revealed no differences between singleton trial frequencies of 4% and 8%. However, because we did not test possible differences in distractor singleton frequencies in the range between 8% and 20%, it cannot be excluded that the effects of singleton rarity arise only if more extreme ratios of singleton to no-singleton trials are used. Search factors might also be important. Yantis and Egeth's participants searched for a hard-to-detect feature difference that defined the target (vertical among slightly tilted). The targets in the present experiments were defined by form. Form, in turn, is not a basic feature (cf. Wolfe, 1994), but may be viewed as a specific spatial configuration of basic features (horizontal and vertical lines).

The interpretation of results in the literature as supporting the contingent-capture hypothesis has been recently criticized by Olivers and Humphreys (2003). These authors suggested that the effects that are normally attributed to contingent capture may actually (partly) reflect cumulative or averaged effects of feedforward trial-by-trial changes of the weights that are given to perceptual dimensions in the attentional set (cf. Müller, Heller, & Ziegler, 1995). This critique does not apply to the present experiments: Performance with rare target singletons should be relatively unaffected by trial-by-trial changes in the dimensional weightings favouring the target colour. Thus, the present experiments reveal the working of contingent capture unaffected by cumulative trial-by-trial changes.

Many studies of attentional capture had confounded frequency and utility because the singletons' utility has often been operationalized by the relative frequency of trials in which the singleton's and the target's positions coincided (e.g., Jonides, 1981; Yantis & Egeth, 1999; see also Olivers & Humphreys, 2003). Thus, previous observations that capture depends on the contingencies between the singleton's and the target's positions allows for two interpretations: Distractor singletons might not capture attention because their position only rarely coincides with the target's position, or because their position frequently coincides with a nontarget position. For example, if a condition with 80% valid cues is compared with a condition with 20% invalid cues, are differences of cost/benefit ratios in performance due to differences of the cue's being more or less predictive of the target, or to the absolute frequency of cue-target cooccurrences at the same locations? The present experiments show that rareness of a singleton by itself has very little influence on performance, even if rather extreme manipulations of rareness (4% and 8%) are used. By contrast, as was assumed in many studies, the ratio of target as compared with that of distractor singletons had a large influence on the amount of capture by the singletons.

The present experiments also shed some light on the conditions of surprise capture, that is the capturing of attention to the first and unannounced presentation of a singleton during a visual search task. For example, Horstmann (in press; see also Horstmann, 2002) showed that a colour singleton captures attention on its very first and unexpected presentation after repeated presentations of no-singleton displays, when the singleton-target SOA was 400 ms or 600 ms, but not if it was 200 ms or shorter (see also Gibson & Jiang, 1998). Because participants were not informed about the occurrence of the singleton in these studies, the attentional shift was clearly unintended.

Horstmann (2002, in press) hypothesized that expectancy discrepancy is an important precondition for the surprise-capture effect. The present experiments provide a control condition for those experiments, testing the possibility that rareness, rather than expectancy discrepancy, is the main factor for the surprise-capture effect. In the present experiments, participants were fully informed about the rare singletons and their utility, and both of these aspects were thus fully expected. The present results show that the time course of the singleton's attentional effect under these conditions is completely different from that of surprising singletons, implying that different mechanisms underlie the two phenomena.

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