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ORIGINAL ARTICLE

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The time course of intended and unintended allocation of attention

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Abstract According to the contingent involuntary orienting hypothesis, only stimuli that match the attentional control settings based on intentions capture attention. In contrast, the surprise-capture hypothesis states that expectancy-discrepant stimuli can capture attention even if they do not match the control settings, implying unintended capture. The purpose of this study is to investigate whether unintended and intended attentional shifts are characterized by different time courses, indicating different underlying mechanisms. An unintended attentional shift was tested by the first, unannounced presentation of a color singleton at the location of a visual search target, and intended shifts by the following repeated presentations of a predictive singleton. Differences in time course were revealed by varying the stimulus onset asynchrony (SOA) between singleton and target. Results showed that accuracy with expected singletons was barely affected by SOA, whereas SOA strongly affected accuracy with the unexpected singleton. The results are interpreted as supporting the surprise-capture hypothesis. It is furthermore argued that a division of labor between contingent capture and surprise in the control of attention supports adaptive behavior.

Introduction

Attentional capture is a means by which information previously unnoticed becomes conscious and available to decision-level information processing. One domain for studying attentional capture has been the localization of a singleton in visual search (Bacon & Egeth, 1994; Chastain & Cheal, 1998; Cheal & Chastain, 1998; Folk, Remington, & Johnston, 1992; Gibson & Jiang, 1998; Gibson & Kelsey, 1998; Horstmann, 2002; Jonides & Yantis, 1988; Nothdurft, 2000; Theeuwes, 1992; Theeuwes & Burger, 1998; Yantis & Egeth, 1999; Yantis & Jonides, 1988). A singleton is a stimulus that differs on a basic perceptual dimension such as color, brightness, orientation, size, etc., from its surroundings that are homogeneous in their respective dimensions (e.g., one red element among several green elements). In visual search tasks, several stimuli (e.g., letters) are presented together, and the observers' task is to search for specified targets (e.g., H). If the target of the search is a singleton, it can be located quickly and apparently without effort. Phenomenally, it appears to "pop out" of the display; behaviorally, the time to localize the singleton is independent of the number of surrounding elements. This efficiency of singleton search provides prima facie evidence that the singleton captures attention rather than it being located through search that requires effort.

Although the efficiency of singleton search satisfies one of the classical criteria of automatic processing (Posner & Snyder, 1975), it has been found not to depend solely on visual saliency. In addition, attending to a singleton depends critically on the attentional set adopted by the observer. The attentional set (or attentional control setting, cf. Folk et al., 1992) in turn is determined by the goals and intentions of the observer in a given task. A singleton can be used to guide search very efficiently when there is some incentive to do so (e.g., when the singleton's position is a good predictor of the target's position). In contrast, if the singleton is irrelevant to the task (i.e., does not help in finding the target), it can often be easily ignored (e.g., Jonides & Yantis, 1988; Yantis & Egeth, 1999; but see Kim & Cave, 1999; Theeuwes, 1992, 1994; Theeuwes & Burger, 1998; Theeuwes & Godijn, 2001). This variant of attentional capture is usually referred to as contingent capture, indicating that capture is contingent on the attentional set (Folk et al., 1992).

The contingent involuntary orienting hypothesis as stated by Folk et al. (1992, 1993), however, goes beyond

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these results and states that *all* instances of attentional shifts are of the contingent-capture variant: "Our contingent involuntary orienting hypothesis states that all involuntary shifts of attention are ultimately contingent on variable internal control settings" (Folk et al., 1993, p. 682). In particular, this hypothesis entails that even apparently involuntary shifts of attention are ultimately due to a *match* between characteristics of the attention-capturing object and the attentional control setting of the observer. Attentional capture occurs only if observers intentionally look for stimuli that share features with the attention-capturing object.

Much of the controversy instigated by the contingent involuntary orienting hypothesis focused on whether attentional capture by an object appearing for the first time is an exception to the hypothesis (e.g., Jonides & Yantis, 1988; Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001) or not (e.g., Ansorge & Heumann, 2003; Folk et al., 1992, 1993; Gibson & Kelsey, 1998). At the same time, there appears to be considerable consensus that the hypothesis is a powerful explanation for attention to color, brightness, size, or orientation singletons (e.g., Folk et al., 1992; Folk & Remington, 1998; Gibson & Jiang, 1998; Yantis & Egeth, 1999), although it has been shown that completely task-irrelevant color singletons induce small reaction time (RT) costs (for example, Theeuwes, 1992, 1994; Theeuwes & Burger, 1998; Theeuwes & Godijn, 2001), which are not readily explained by the contingent capture hypothesis (but see Folk & Remington, 1998).

An objection of a more general kind is that the contingent involuntary orienting hypothesis in its most radical form is not entirely justified by the experimental data presented by Folk et al. (1992) and others who showed that the content of intentions modifies (in the extreme enables or disables) attentional capture. Because intentions concerning the singleton were present in all conditions, this approach does not test whether intentions are necessary for attentional capture, it tests whether they are sufficient to alter attentional capture.

A proper test of the hypothesis that intentions are necessary for attentional capture appears to be one that guarantees the complete absence of intentions concerning the attention-capturing stimulus. Almost all experiments to date, however, induced clearly definable intentions concerning the events tested to capture attention, i.e., the participants were always fully informed about the possibility of singletons and about their usefulness, uselessness, or obtrusiveness for their task, and participants were assumed to form intentions to attend to or to ignore the singleton (e.g., Bacon & Egeth, 1994; Folk et al., 1992; Jonides & Yantis, 1988; Nothdurft, 2000; Theeuwes & Burger, 1998; Yantis & Egeth, 1999). Although this procedure provides information about the important question of the extent of voluntary control over visual attention, it does not directly test the question whether intentions are necessary for an orienting of attention.

Gibson and Jiang (1998) were probably the first to directly test whether intentions are necessary for attentional capture by singletons in visual search.[1] In particular, they examined whether an *unannounced* singleton captures attention at its very first presentation. This condition provides a straightforward means of testing intentions as necessary conditions, because it precludes that an attentional set toward the singleton is developed, and thus satisfies Yantis' (1983) criterion for unintended attentional capture as being independent of the intentions or beliefs of the observer.

Gibson and Jiang (1998, Experiment 1) presented an array of eight letters and the task was to indicate whether the array contained an H or a U. The letters flashed only briefly (for 86 ms), and accuracy (percentage of correct answers) was the dependent variable. To prevent participants from forming an attentional set toward singletons (cf. Bacon & Egeth, 1994), all letters were composed of vertical and horizontal line segments, and the targets could not be distinguished from the remaining letters (the distractors) on the basis of a single featural discontinuity.

The single experimental block of trials comprised two phases. In the first phase, all letters were of the same color and no additional cue to the position of the target was given. In these *pre-critical trials*, search was assumed to require a demanding serial search, resulting in a performance that was less than perfect in combination with the restricted presentation time of the letters. In the second phase, the target was always presented in a color different from the distractors, i.e., the target was a color singleton. The presentation of the singleton was not announced to the participants prior to or during the experiment, and no other variables indicated a change in the display to the participants. Thus, in the first trial of the second phase (the *critical trial*), the presentation of the singleton was completely unexpected. The participants did not know about the occurrence of the singleton prior to its first presentation or that it was a feature of the target. Gibson and Jiang (1998) reasoned that according to the contingent capture hypothesis, no attentional capture by the singleton should occur, because the attentional set was to attend to the letter display as a whole, and not to attend to a singleton. For the remaining trials of the second phase (the *post-critical trials*), it was assumed that the observers would ultimately notice the singleton and its usefulness. For that reason, the observers should change their attentional set and intent to attend to the position of the singleton in order to quickly identify the target. Gibson and Jiang's results turned out to be consistent with the contingent-capture hypothesis. Participants' performance was not better in the critical trial than in the preceding pre-critical trials, but significantly worse than in the following post-critical trials.

[1] Actually, Wilcocks (1928), following a hypothesis by Selz (1922), conducted the first experiments using unexpected singletons, but he did not use a visual search task in the strictest sense.

As such, Gibson and Jiang (1998) provided a direct test of the claim that intentions are necessary for attentional capture. However, their procedure presupposed attentional capture to be as fast in the critical trial as in the following post-critical trials. This assumption is sensible if attentional capture in these two conditions is assumed to be mediated by the same underlying mechanism. In contrast, if this assumption is not valid (and unintended and intended attentional capture are in fact mediated by different mechanisms), it could well be that the two types of attentional capture have different time-courses. In particular, if unintended attentional capture is slower than intended attentional capture, the orienting might have occurred too late to improve performance in the letter identification task, given the very restricted presentation time of the letters following the onset of the singleton.

A mechanism for attentional capture under the conditions examined by Gibson and Jiang that is different from contingent capture has been proposed by Horstmann (2002), based on a model of the conditions and concomitants of surprise (e.g., Meyer, Niepel, Rudolph, & Schützwohl, 1991; Meyer, Reisenzein, & Schützwohl, 1997; Niepel, Rudolph, Schützwohl, & Meyer, 1994; Schützwohl, 1998; see also Prinz, 1983, 1990; Selz, 1922; Wilcocks, 1928). In this account, the singleton in the critical trial was expectancy discrepant, because in the pre-critical trials, only color-homogeneous displays were presented, and the participants were not informed about the stimulus change. Expectancy-discrepant (or schema-discrepant) stimuli, in turn, elicit a surprise response that entails an interruption of ongoing processing and an orienting of attention to the surprise eliciting stimulus, resulting in decision level processing of that stimulus.[2] The latency of the surprise-response has been found to be a few hundred milliseconds for a stimulus change of the type used in the study by Gibson and Jiang (1998). For example, Meyer et al. (1991; see also, Niepel et al., 1994) found that interference produced by a surprising visual event in a choice-reaction task is stronger with a 500-ms SOA than with a 0-ms SOA between the surprise stimulus and the choice-reaction task stimulus. To conclude, surprise capture and contingent capture may have different time courses, with surprise capture being slower than contingent capture.

Concerning the hypothesized (relative) tardiness of the surprise response, Horstmann (2002) modified Gibson and Jiang's (1998) procedure. Instead of presenting the singleton color as a characteristic of the target letter, color was a characteristic of squares that were presented as backgrounds for the letters. With this change it was possible to present the singleton prior to the letters (see also, Chastain & Cheal, 1998; Cheal and Chastain, 1998). When no preview of the squares was given (squares and letters appeared simultaneously), Gibson and Jiang's (1998) results were replicated. In contrast, with a preview duration of 500 ms (the appearance of the squares preceded the appearance of the letters with an SOA of 500 ms), accuracy in the critical trial was significantly higher than in the preceding pre-critical trials, but not significantly different from the following post-critical trials. Thus, a shift of attention was demonstrated when the procedure allowed for the orienting of attention to be somewhat slower for the unexpected singleton than for the expected singletons. Further experiments (Horstmann, 2002, Experiment 3; Horstmann, 2004) confirmed the finding of attentional capture by an unexpected color singleton using a speeded search task with a set-size variation and RT as the dependent variable.

The objective of the present experiments was to examine the time course of surprise capture by systematically varying the preview duration. More precisely, with a time-course analysis, the speed of an attentional shift to an unexpected singleton is measured and compared with the speed of a shift to an expected singleton. It is assumed that contingent capture by an expected predictive singleton has a time course different from surprise capture by an unannounced and expectancy-discrepant singleton: An expected, but not an unexpected singleton could be used immediately after its onset (Gibson & Jiang, 1998; Horstmann, 2002). Thus, a demonstration of different time courses supports the distinction between contingent capture and surprise capture, as well as the hypothesis of different underlying mechanisms.

A time-course analysis is also of interest with respect to the hypothesis that singletons generally capture attention, even in the absence of intentions. Proponents of this singleton-capture hypothesis have hypothesized singleton capture to be very fast, occurring within the first 100 ms of stimulus onset (e.g., Theeuwes & Godijn, 2001; Kim & Cave, 1999). Although the results with the 0-ms SOA (Gibson & Jiang, 1998; Horstmann, 2002) already appear to contradict this prediction for an unexpected singleton, it is possible to argue that the 86-ms exposure of the stimuli was just not long enough to allow performance to benefit from singleton capture in the paradigm used. Therefore, using SOAs intermediate to those used in Horstmann (2002) is a means to test this account. Lastly, independent of this attempt to differentiate empirically between variants of attentional capture, unveiling the time course of surprise capture is important in itself.

The present experiments extended the earlier ones (Horstmann, 2002) in two respects. First, a refined temporal resolution was used. Second, preview durations and absence vs. presence of preview were de-confounded. In the present experiments, previews of different durations were given: 200, 400, and 600 ms in Experiment 1, and 0, 100, 200, 400, 500, and 600 ms in Experiment 2. It might be noted at this point that although an even finer-grained temporal resolution would be of advantage for a

[2]It should be emphasized that it is not supposed that the attentional shift is caused by the feeling of surprise. Instead, surprise is conceived of as a syndrome of responses to unexpected (schema-discrepant) events, with one of the components of this syndrome being the attentional shift.

time-course analysis, unintended attentional capture (as operationalized here) is bound to a between-participants design with a single datum (i.e., the critical trial) for each participant. Thus, because each experimental condition requires a substantial number of naïve participants, the number of SOAs to be examined is often smaller than it would be in a within-participants design.

Experiment 1 was a straightforward extension of Horstmann's (2002) Experiment 1, with constant SOAs throughout the experiment. Because constant SOAs throughout the experiment may induce subtle differences in strategies, Experiment 2 used varying SOAs.

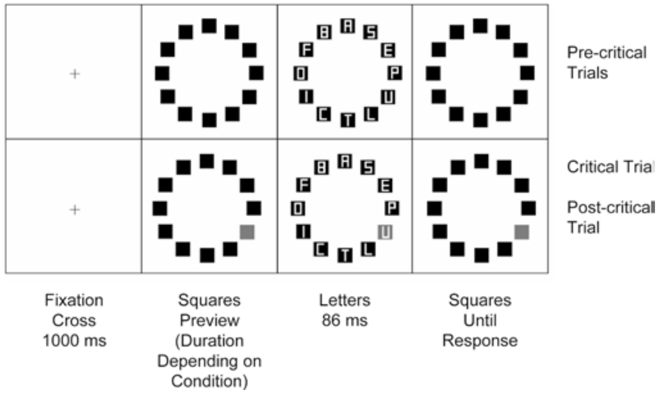

Fig. 1 Trial structure in the experiment. Time runs from left to right. In the experiment, the background and the letters were black, and the squares were red or green (indicated here by *black* vs. *gray*). The only difference between the pre-critical trials (*upper panel*) and the critical trial plus the post-critical trials (*lower panel*) was that only in the latter trials there was a color singleton (on the same location as the target) in each trial (note: the figure is not drawn to scale)

Experiment 1

Methods

Participants and design

Sixty students and visitors at the University of Bielefeld (21 men and 39 women), with a mean age of 24.1 years (SD = 6.2 years) participated for a small monetary incentive. Each participant was randomly assigned to one of the three preview durations of 200, 400, or 600 ms. Each participant received only one preview duration, which was therefore constant over the entire experiment.

Apparatus, stimuli, and procedure

ERTS (BeriSoft Cooperation, Frankfurt, Germany), run on a computer equipped with a 80486 CPU, was used for event scheduling and data registration. A 15" color monitor was used for stimulus presentation and a standard keyboard served to register the responses. In each trial, following a fixation cross, 12 colored squares (1.2°×1.2°; viewed from a distance of 57 cm) appeared in the 12 o'clock positions of an imaginary circle with a radius of 3.4° (Fig. 1). After a fixed SOA of 200, 400, or 600 ms (depending on condition), 12 black (0 cd/m^2) letters (0.7°×0.8°), composed of horizontal and vertical line segments only, were presented in the squares for 86 ms. With this composition of the letters, the target letters were not distinguishable from the non-target letters on the basis of a single feature contrast (cf. Gibson & Jiang, 1998). This was intended to discourage any strategic tendency to search for a singleton, because such a "singleton detection mode" had been made responsible for apparently unintended orientation of attention by Bacon and Egeth (1994). The squares were visible until a response was registered. The reason for presenting the squares for a longer duration was to ensure that they were presented long enough to allow the formation of a stable schema or expectancy concerning the squares' colors.

The participants' task was to determine which of two possible target letters (H or U) appeared, and to press a key accordingly. The instructions emphasized accuracy of response and explained that speed was only of secondary importance. Errors were immediately followed by error feedback, consisting of a short tone. Participants were instructed to fixate the center of the screen (indicated by a fixation cross) throughout each trial, because this was considered the best strategy for detecting the target in as many trials as possible given the limited presentation time of the letters. They were informed, however, that the task was difficult and that there were many trials in which they would not detect the target. In the pre-critical trials, which comprised 48 experimental trials preceded by 24 practice trials, all squares were of the same color. They were followed by 48 trials, where one square appeared in a different color. The positions of this singleton square and the target letter always coincided. The first trial with a singleton square was the critical trial. Each target appeared equally often at each position, using a new random sequence for each participant. The experiment flowed continuously from one segment to another, and the participants were not informed that one square would be presented in a different color or that it would indicate the target position. For half of the participants, the singleton square was red (18 cd/m^2) and the remaining (non-singleton) squares were green (87 cd/m^2); for the other half, the color assignment was reversed. The fixation cross and the messages that appeared prior to and following the practice trials, had the same color as the non-singleton squares. The colors were not matched for luminance; instead, it was assumed that the subjectively large difference in color would be more important than the luminance difference (e.g., Folk et al., 1992).

Results and discussion

Figure 2 shows the time course of attentional deployment as measured by accuracy in the letter search task 200, 400, or 600 ms after the onset of the preview array. In the pre-critical trials, where the array contained no singleton and thus no element would capture attention, the mean proportion of correct responses was low and unaffected by preview duration, $F(2, 57) < 1$. In contrast, in the post-critical trials, where the target letter always appeared at the same location as the singleton in the preview array, the very high mean proportion of correct responses indicate attentional capture, as predicted by the contingent capture hypothesis. The slight linear trend with preview duration was non-significant, $F(2, 57) = 2.1$, $p > .1$, however. Most importantly, the first and unannounced presentation of the singleton in the critical trial did not result in attentional capture with a preview of 200 ms, but did with previews of 400 and 600 ms. Fisher's exact test revealed that the proportion of correct responses in the critical trial differed significantly between the SOAs of 200 and 400 ms, $p < .05$, but not between the SOAs of 400 ms and 600 ms, $p = .99$.

A second analysis was done to examine whether performance in the critical trial was most similar to the preceding pre-critical trials or to the following post-critical trials. Evidently, mean performances in the three segments are not directly comparable because of possible serial-order effects due to practice. To account for serial-order effects, the proportion of correct responses in the critical trial was statistically predicted by means of linear regression, with trial number as the predictor (Gibson & Jiang, 1998; Horstmann, 2002). Separate linear regressions were computed for each preview duration, and on the basis of the performance in both the pre-critical trials and in the post-critical trials (Table 1). Furthermore, a 95% confidence interval for the population proportion of correct responses was computed on the basis of the proportion of correct responses actually obtained in the critical trial (see Table 1). This analysis revealed that for the 200-ms preview duration, the confidence interval included the proportion of correct responses predicted from the pre-critical trials, but not that predicted from the post-critical trials, while the opposite was true for the 400- and 600-ms preview durations. That is, performance was not different from the pre-critical trials when the preview duration was 200 ms, indicating no attentional capture. In contrast, performance in the critical trial was as good as in the post-critical trials with preview durations of 400 and 600 ms durations, indicating attentional capture of comparable efficiency.

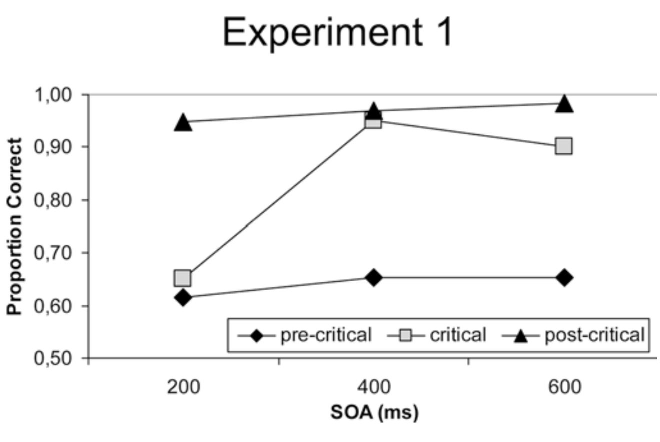

Fig. 2 Experiment 1: proportion of correct answers for the pre-critical trials, the critical trial, and the post-critical trial, depending on preview duration (stimulus onset asynchrony [SOA])

Table 1 Main results from Experiment 1. Performance was regressed on trial number (1st–48th in the pre-critical trials and 50th–96th in the post-critical trials) for each stimulus onset asynchrony (SOA). The regression equations derived from the pre-critical and post-critical trials were then used to predict performance in the critical (49th) trial. The obtained proportion of correct responses in the critical trial is given for each SOA, together with the 95% confidence interval (CI) for the population mean proportion of correct responses in parentheses

SOA	Pre-critical trial prediction	Proportion correct in the critical trial (CI)	Post-critical trial prediction
200 ms	.58	.65 (.43–.82)	.93
400 ms	.68	.95 (.76–.99)	.95
600 ms	.64	.90 (.70–.97)	.97

Evidently, participants were attending to the singleton in the 400- and 600-ms SOA conditions. In contrast, participants in the 200-ms SOA condition did not attend to the singleton, or at least not as soon as the letters appeared. Examining the performance in the trials immediately following the critical trial can be informative in this respect. If the participants noticed the singleton in a given trial, they may intentionally look for a second occurrence of a singleton in the next trial; in this case, performance in the following trials should be quite good. In contrast, if the participants did not notice the singleton in the critical trial, there is little reason to expect good performance in the next trial. In fact, the proportion of correct responses in the first five post-critical trials of the 200-ms SOA condition was quite high right from the beginning (.90, .95, .90, .85, .95), indicating that the participants noticed the singleton in the critical trial. In interpreting this result, however, it should be borne in mind that the colored squares were visible until a response had been made (which was considerably longer than 200 ms). Thus, this result may indicate a dissociation between attentional capture by and awareness of the singleton. However, a more simple account would be that the singleton captured attention in the critical trial even in the 200-ms SOA condition, but not sufficiently quickly to improve performance in that trial.

To summarize, the data are fully compatible with the results obtained by Gibson and Jiang (1998) and Horstmann (2002), which indicated that attentional capture by an unannounced color singleton is not revealed with short SOAs, but that a positive SOA between the onset of the singleton and the onset of the target of the search is a necessary precondition to revealing attentional capture. Furthermore, the present data complement the previous ones, indicating that attentional capture occurs about 400 ms later in the critical trial than in the post-critical trials.

Experiment 2

A possible objection to Experiment 1 is that different SOAs may not only probe the locus of attention at different points in time following the onset of the display, but may simultaneously induce subtle differences in strategies between the SOA conditions, when SOAs are blocked as in Experiment 1. These differences in strategies might well be used to explain the differences in critical trial performance, thus questioning the conclusion that there are differences in time course between intended and unintended attentional capture.

The obvious remedy for this possible confounding of SOA and strategy is to present different SOAs intermixed rather than blocked in the pre-critical trials. This was done in Experiment 2. Experiment 2a tested the SOAs of 200 and 400 ms, Experiment 2b tested the SOAs of 100 ms and 500 ms, and Experiment 2c tested the SOAs of 0 ms and 600 ms. Note that the pairing of the SOAs was designed in such a way that the mean SOA was 300 ms in all three experiments.

Method

Participants

Forty-eight students participated in Experiments 2a, 2b, and 2c each. The mean age of the 6 men and 42 women in Experiment 2a was 24.4 ($SD = 7.2$) years, that of the 22 men and 26 woman in Experiment 2b was 25.6 ($SD = 6.4$) years, and that of the 16 men and the 32 women in Experiment 2c was 24.8 ($SD = 6.3$) years. They were paid €1 for their participation, which lasted 5–10 min.

Apparatus, stimuli, procedure, and design

These were the same as in Experiment 1 except for the following modifications:

a) The SOAs between the onsets of the squares and the letters varied randomly in the 48 pre-critical and the 48 post-critical trials, with the mean SOA being fixed at 300 ms (SOAs were 200 and 400 ms in Experiment 2a, 100 and 500 ms in Experiment 2b, and 0 and 600 ms in Experiment 2c
b) SOA was varied between participants in the critical trial, such that half of the participants in each experiment received one of the two SOAs
c) A different monitor was used (a 19'' Samsung SyncMaster 959 NF)
d) The experiment was interrupted after the critical trial, where participants were asked whether they had noticed something in the last trial that differed from the preceding trials, and if they had, whether they had seen that the target coincided with the singleton. The verbal reports were collected to assess the participant's awareness of characteristics of the critical trial.

Results

A first analysis concerned the effect of SOA on the accuracy data in the pre-critical trials and in the post-critical trials. There were no significant differences between the SOAs regarding the proportion of correct responses in the pre-critical trials of Experiments 2a and 2b—Experiment 2a: $t(47) < 1.0$; Experiment 2b: $t(47) < 1.0$. The mean proportion of correct responses was .63 in both Experiments 2a and 2b. In Experiment 2c, the proportion of correct answers differed significantly in the pre-critical trials, $t(47) = 3.0$, $p < .01$, reflecting superior performance with the 600 ms SOA over the 0 ms SOA (.64 vs. 58).

In the post-critical trials, the proportion of correct responses was slightly lower with the shorter SOAs than with the longer SOAs—Experiment 2a: .95 vs. .97, $t(47) = 2.7$, $p < .05$; Experiment 2b: .92 vs. .96, $t(47) = 3.9$, $p < .001$; Experiment 2c: .88 vs. .98, $t(47) = 7.5$, $p < .001$.

Figure 3 shows the proportion of correct responses for the critical trial; for comparison, the proportion of correct responses obtained for the pre-critical trials and for the post-critical trials of the same SOAs are also depicted. A Chi-squared test revealed a significant difference between the two SOAs in the critical trial in Experiment 2c, χ^2 (1; $n = 48$) = 11.1, $p < .001$), reflecting a higher proportion of correct responses with the 600-ms SOA than with the 0-ms SOA (.96 vs. .54). The corresponding analysis revealed a marginally significant difference in Experiment 2b, Chi-squared (1; $n = 48$) = 3.4, $p = .07$), reflecting better performance with the 500-ms SOA than with the 100-ms SOA, (.92 vs. .71). No significant difference was obtained between the two SOAs

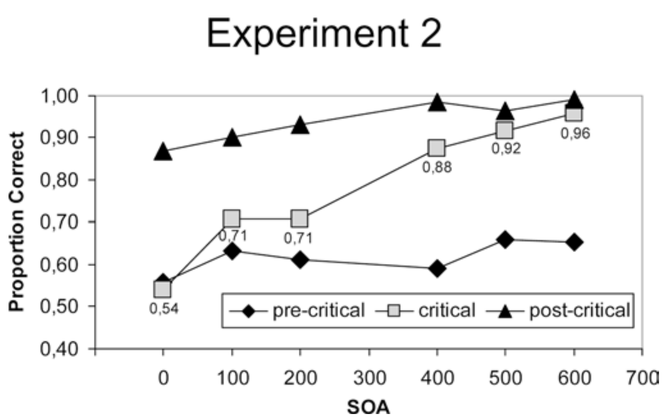

Fig. 3 Experiment 2: proportion of correct answers for the pre-critical trials, the critical trial, and the post-critical trial, depending on preview duration (SOA)

Table 2 Main results from Experiment 2. Performance was regressed on the ordinal number of the occurrence (1st–24th in the pre-critical trials and 26th–49th in the post-critical trials) of the same SOA as in the critical trial. In addition to the performance in the critical (25th) occurrence of the relevant SOA as predicted on the basis of the pre-critical and post-critical trials, the regression coefficients are given, and the 95% confidence interval (CI) for the critical trial that was based on the actual performance for the respective SOA condition

SOA (ms)	Pre-critical trial prediction		CI critical	Post-critical trial prediction	
	Regression	Predicted		Predicted	Regression
0	$y = 0.0005x + 0.55$	.68	.35–.71	.89	$y = -0.0014x + 0.92$
100	$y = 0.0003x + 0.63$	.70	.51–.85	.83	$y = 0.0060x + 0.68$
200	$y = 0.0042x + 0.56$	.66	.51–.85	.90	$y = 0.0040x + 0.78$
400	$y = 0.0027x + 0.56$	.63	.69–.96	.97	$y = 0.0009x + 0.95$
500	$y = 0.0053x + 0.59$	.72	.75–.98	.94	$y = 0.0021x + 0.89$
600	$y = 0.0058x + 0.58$	.73	.80–.99	.98	$y = 0.0005x + 0.97$

in the critical trials of Experiment 2a, Chi-square (1; $n = 48$) < 1, owing to the fact that the increase in the proportion of correct responses with the 400-ms SOA compared with the 200-ms SOA was comparably small, amounting to only .09.

As in Experiment 1, confidence intervals were computed for the proportion correct in the critical trial, and it was tested whether the values statistically predicted by means of linear regressions from the proportion correct in the pre-critical and the post-critical trials would fall within this confidence interval. For each SOA condition, only those 24 pre-critical trials and 24 post-critical trials that corresponded to the SOA in the critical trial were used, and performance was regressed on the ordinal number of occurrence of the respective SOA (i.e., first, second, third, etc., occurrence of the SOA). Table 2 gives an overview of the results; to enhance readability, the columns are ordered by SOA rather than by experiment.

The confidence intervals for the proportion correct in the critical trial included the predicted proportion of correct responses based on the pre-critical trials for the 0-ms, 100-ms, and 200-ms intervals, while it included the predicted proportion correct based on the post-critical trials for the 100-ms, 500-ms, and 600-ms SOAs. Performance with the 400-ms SOA differed significantly from both the performance predicted by the pre-critical and the post-critical trials, although it might be noted that the confidence interval just fell short of including the performance predicted by the post-critical trials. To summarize, the results are in accordance with those of Experiment 1 in that performance in the critical trial did not differ significantly from the pre-critical trials for the short SOAs (< 400 ms), while it was similar to performance in the post-critical trials for long SOAs (> 400 ms). However, in contrast to Experiment 1, the results in the present experiment did not reveal an abrupt performance change between 200 and 400 ms following display onset, but instead a nearly linear relationship between SOA and performance (see Fig. 3).

Following the critical trial, participants were asked whether they had noticed any differences in comparison to the preceding trials, and if they had, whether they had also seen the target. Each answer was categorized into one of three categories:

a) Participants correctly reported the singleton and said that they had seen the target
b) Participants correctly reported the singleton, but reported not having seen the target
c) Participants did not report the singleton

Table 3 shows the frequencies of the three categories for each SOA (to enhance readability, the columns are ordered by SOA rather than by experiment); this presentation reveals that:

a) Nearly all participants (83–100%) noticed the singleton in the critical trials
b) The percentage of the participants reporting having seen the target was approximately a linear function of SOA

Statistical testing, however, was done by comparing the distributions for the two SOAs that were presented intermixed in the pre-critical and the post-critical trials. This analysis revealed no difference between the two SOAs in Experiment 2a (200 vs. 400 ms), χ^2 (2; $n = 48$) < 1, but significant differences in Experiment 2b (100 vs. 500 ms), χ^2 (2; $n = 48$) = 11.0, $p < .01$, and

Table 3 Verbal reports (in percentages) concerning the critical trial in Experiments 2a–c

	0 ms	100 ms	200 ms	400 ms	500 ms	600 ms
Singleton noticed						
Target noticed	25	21	42	42	67	75
Target not noticed	75	71	42	46	33	25
Singleton not noticed	0	8	17	13	0	0

Experiment 2c (0 vs. 600 ms), χ^2 (2; $n = 48) = 12.0$, $p < .001$.

Discussion

The basic results from Experiment 1 were replicated. Proportion correct in the critical trial was not significantly different from performance in the pre-critical trials for the short SOAs (< 400 ms). In contrast, for the long SOAs (> 400 ms), performance in the critical trial was as high as in the post-critical trials. For the 400-ms SOA, performance in the critical trial differed from both the performance in the pre-critical and in the post-critical trials. In contrast, the time course of attention shifts to expected singletons was only moderately affected by SOA.

Qualitatively, the shape of the functions relating performance to SOA was slightly different in Experiments 1 and 2. In particular, the slope of the function in Experiment 1, where the transition between attending or not attending to the singletons' position occurred between the two SOAs of 200 and 400 ms, was steeper than in Experiment 2, which revealed a nearly monotonic increase in the proportion of correct responses over the entire range of SOAs examined (see Table 2). This lends support to the concern acknowledged in the introduction that different constant SOAs may influence the participant's strategies with respect to the processing of the displays. For example, with a fixed 200-ms SOA, participants may have been more set to process the task relevant features of the letters, which may have impeded the processing of other (and task-irrelevant) aspects of the display, such as color. In contrast, with a variable SOA of 300 ms on average, the priority of the task-relevant features would have peaked somewhat later. The resulting slight advantage for the color processing in the first 100 ms or so after the onset of the display would explain that performance in the 200-ms SOA condition was better in Experiment 2 than in Experiment 1.

However, because in Experiment 2 all participants had variable SOAs of the same average duration of 300 ms, their strategies should have been roughly the same in all conditions, i.e., differences in strategies cannot explain the time course in Experiment 2. Thus, the important result of Experiment 2 is that the differences in time course between attention shifts to expected and unexpected singletons are not an artifact of the method, and the results are in agreement with the hypothesis that different mechanisms underlie shifts of attention instigated by expected and by unexpected singletons. Furthermore, together with Experiment 1, the results suggest that with an SOA of about 400 ms or little more, the performance in the critical trial becomes as good as in those with expected singletons.

The participants' reports immediately following the critical trial revealed two main results. First, the verbal reports of having seen the target closely corresponded to the behavioral data, as both showed an increase in SOA. Second, only very few participants did not notice the color singleton at all, even in those conditions where they had not found the target. Inattentional blindness (e.g., Mack & Rock, 1998) was apparently rare in the present experiment, and, if present, unrelated to the singleton-target SOA. This might be interpreted as supporting the distinction between explicit measures of inattentional blindness (i.e., asking directly for awareness of the unexpected event) and implicit measures (i.e., observing changes in performance), as proposed by Simons (2000). For an interpretation of this result, however, remember that the colored squares were visible even after the disappearance of the letters until the response was made. It is thus possible that the implicit and explicit measures of inattentional blindness would be associated, rather than dissociated, if the colored squares disappeared together with the target letter.

General discussion

The present experiments revealed differences in time course between the attentional shifts to expected and unexpected stimuli. With expected predictive singletons, the singleton-target SOA affected performance only weakly, while with unexpected predictive singletons, there was a strong effect of SOA on performance. This pattern of results indicates that the attentional shifts to expected and to unexpected singletons have different time courses; in particular, an attentional shift to an unexpected singleton occur somewhat later than a shift to an expected predictive singleton. While the expected predictive singleton improved performance even with a 0-ms SOA, significant performance increments with unexpected predictive singletons occur only with SOAs of 400 ms or more.

The differences in time course suggest differences in underlying mechanisms. Attentional shifts to expected singletons can be explained by the contingent involuntary orienting hypothesis (Folk et al., 1992, 1993). According to this account, an observer can quickly orient to a target by having the attentional control system set to features that uniquely identify it. This setting is done "offline," i.e., before the stimulus appears, and it is done intentionally on the basis of beliefs about the usefulness of target features with respect to the observer's goals and intentions. When the stimuli appear in a given trial, those features that correspond to the attentional control settings attract attention. This "online" attentional response to the stimulus is involuntary, i.e., results from a direct interaction between the stimulus and the attentional control settings, explaining the speed and the efficiency of the attentional shift.

In contrast, for an unexpected singleton in the critical trial, there was no intention of shifting attention to the position prior to its occurrence (Gibson & Jiang, 1998). In this sense, at least, the shift of attention is unintended. Moreover, because the observer is aware of the usefulness of the singleton only after he or she has attended to the singleton, the attention shift must have been independent of the observer's goals and beliefs, satisfying an important criterion for exogenous control of attention (e.g., Yantis, 1993).

It was proposed in the Introduction that a surprise-attention hypothesis can explain the attentional capture effect obtained in the critical trial. According to this account, an expectancy discrepancy (or schema discrepancy) is an independent source of attentional priority given to stimuli, and for this reason, surprising stimuli can capture attention (given that the discrepancy can be determined prior to attentional selection).[3] Previous experiments on surprise have indicated that the surprise response needs a few hundred milliseconds to develop for expectancy-discrepant events similar to those used here. For example, Meyer et al. (1991; see also Niepel et al., 1994) found that dual-task interference instigated by a surprising stimulus change was stronger with a 500-ms SOA than with a 0-ms SOA or with a 1,000-ms SOA.

Analytically, at least two steps are necessary to shift attention toward a discrepant stimulus. First, the discrepancy must be determined, and second, a shift of attention must be triggered. The observed delay in shifts to unexpected compared with expected singletons can be attributed to either or both of these steps. I will first discuss the possibility that the detection of the discrepancy is the source of the delay. The pursuit of this possibility can be justified by acknowledging that the processing of features, objects, or scenes, must be slower if they are unexpected rather than expected. This assumption is at the heart of several theories that use expectations or expectation-similar concepts to explain aspects of cognition (e.g., Di Lollo, Enns, & Rensink, 2000; Neisser, 1976; Rumelhart, 1984). For example, Neisser's (1976) perceptual-cycle hypothesis assumes that observers have schemas or expectations as to what belongs to the scene (i.e., which objects with what characteristics should be present) that are used to guide attention. Attention then picks up information from the scene, which in turn fleshes out or modifies the schema. Unexpected information must first trigger a new perceptual cycle to get "seen" (see also Di Lollo, Enns, & Rensink, 2000; Most & Simons, 2001). Unless this occurs, there is "inattentional blindness" for the unexpected stimulus. Research on this phenomenon has shown that unexpected changes in the stimulation occasionally remain unnoticed for considerable time periods (e.g., Neisser, 1976, 1979; Most, Simons, Scholl, Jimenez, Clifford, & Chabris, 2001; Simons & Chabris, 1999), although an important condition for sustained inattentional blindness is probably similarity to stimuli that are expected to be ignored (Most et al., 2001), rather than unexpectedness per se.

With regard to the second possibility that the delay is due to the triggering of the attentional shift, there are two possibilities. First, it could be due to conflicts within a single mechanism controlling attentional shifts. When a surprising stimulus is presented during a visual search task, a request for attention to the surprising stimulus has to concur with the planning and execution of attention shifts during the search task. This response conflict might delay the response to the surprise singleton. Second, the delay may be interpreted as reflecting the formation of an intention, implying that the shift toward the surprise singleton might not at all be involuntary, but just unplanned. In other words, it might be thought that surprise capture is only unintended with respect to the intentions present *prior* to the singleton's presentation in the critical trial, but that in the critical trial, the detection of the discrepant singleton is followed by the generation of a new intention: To attend to the singleton. Unfortunately, the present data have little to say about this and (to my knowledge) nothing is known about the speed of intention formation. Thus, at present, it appears to be more a matter of taste as to the plausibility that a discrepancy is detected (without intention, as should be borne in mind), an intention is formed to attend to the discrepancy, and an attentional shift is executed, all in about 400 ms. The reliability of the attentional shift (i.e., the very high proportion of participants who had shifted attention to the discrepancy with SOAs of 400 ms or more), however, cannot readily be explained by this account. If the attention shift would have been a spontaneous act of will, more variance would have been expected. Remember that the singleton is task irrelevant as it appears for the first time, and that there is no rational reason to attend to it. There is thus little reason to expect such conformity in the attentional response of the participants if it is assumed to be voluntary.

A further point worth considering is the role of eye movements. As eye movements normally have a latency of about 200 ms (e.g., 238 ms for a saccade to a color singleton in Theeuwes, Kramer, Hahn, & Irwin, 1998), it might appear that they could partly explain the poor performance in the critical trial with SOAs of less than 200 ms. For example, it might be argued that within the task used, nearly perfect performance could be reached only if the eyes are moved to the singletons' position. If this were true, the experiments simply revealed the time course of eye movements, but not of attentional capture. This explanation, however, is contradicted by the data. As Table 2 reveals, performance is very high in the post-critical trials even with a 0-ms SOA, indicating that eye movements are not necessary for a high performance in the present task. Indeed, the size of the letters and their excentricity were such that visual acuity was not the limiting factor of performance. The most important limiting factor in the pre-critical trials was the short display duration, which made it impossible to scan all

[3]To what extent this is possible remains to be examined. A good guess, however, appears to be that only basic features, but not their conjunctions, capture attention in the way examined in the present experiments (cf. Treisman Gelade, 1980).

letters. The predictive singleton in the post-critical trials made this limit obsolete, because there was only one item that had to be checked for identity to accomplish the task. However, although participants were instructed to fixate the center of the circle (indicated by the fixation cross) throughout each trial, it is possible that this instruction was not followed by some participants in the post-critical trials (due to equipment limitations, eye movements were not controlled in the experiments). This might explain the moderate increase in performance with SOA in the post-critical trials as revealed in Table 2. To conclude, although eye movements possibly contributed to the time courses observed in the present experiments, they cannot account for the differences in time course between shifts of attention to expected and unexpected singletons.

The current results have implications for hypotheses about attentional control. Consistent with Horstmann (2002), the results indicate that unintended attentional capture exists for surprising singletons and that contingent capture does not exhaust the possibilities. This result squares with a strong version of the contingent involuntary capture hypothesis that attentional capture by singletons necessarily requires the singleton to share features with the attentional set. This strong version of the hypothesis cannot explain the results, because the target was not defined by the singleton color in the pre-critical trials, and the singleton color was therefore not part of the attentional control setting.

Another hypothesis that has been proposed is that new objects capture attention (e.g., Enns et al., 2001; Jonides & Yantis, 1988; Rauschenberger, 2003; Yantis & Hillstrom, 1994). A new object has been operationalized as an object that appears in a position previously unoccupied by any object, as opposed to an old object that results from a change in an already existing object. For example, while a digit can be an old object if it results from removing elements from a figure-eight placeholder, the same digit would be a new object if it were presented in a formerly empty position in space. It is quite obvious that the new object hypothesis cannot immediately explain the present results, because the singleton square was not singled out by a contrast between old and new objects in the sense just described. However, there is of course a sense in which the surprise singleton was new and the distractors were old in the critical trial, such that the new object hypothesis might be modified to subsume not only cases in which an object is perceptually new, but also those where an object is new with respect to a different standard, such as expectancies, as explained in more detail below.

Such a modified new-objects hypothesis converges with the surprise-attention hypothesis, which holds that events capture attention if they are surprising (e.g., Horstmann 2002; Meyer et al., 1991; see also Desai, 1939; Selz, 1922; Wilcocks, 1928). Surprising events, in turn, are often explicated as being unexpected, unknown, novel, unusual, contrary to the natural course of things, rare, improbable, or sudden (cf. Meyer & Niepel, 1994). In an attempt to develop a theoretically useful concept of the characteristics of events that elicit surprise while retaining the ideas expressed in the descriptions listed above, Meyer and co-workers suggested that the discrepancy between an event and the present mental model of the situation (made up of cognitive schemas, cf. Neisser, 1976; Rumelhart, 1984) is the condition that ultimately triggers surprise (Meyer, 1988; Meyer & Niepel, 1994; Meyer et al., 1997; Schützwohl, 1998; see also Prinz, 1990). According to this account, acting presupposes a dynamic mental representation (or model) of the environment (Neisser, 1976; Rumelhart, 1984). This model is dynamic in two respects. First, it is updated continuously in order to always represent the latest stimulation. Second, it is not just used to keep a tally on the present, but to extrapolate into the future, in order to enable action preparation for coming events. In order to prevent the system from acting on the basis of an invalid mental model of the situation, the model is continuously checked for consistency with the impinging stimuli. While minor inconsistencies may often be assimilated into the schema without much effort, major inconsistencies elicit surprise. The surprise response, in turn, entails an interruption of current action and an orienting of attention to the surprising event.

Equipped with this surprise theoretic view, the present results can be explained by assuming that expected and unexpected singletons are processed differently (Horstmann, 2002; Meyer and Niepel, 1994; Schützwohl, 1998). While expected singletons capture attention if their *selection is intended* (contingent capture hypothesis), unexpected singletons capture attention if they deviate significantly from those stimuli whose *perception is expected* (surprise-attention hypothesis), explicitly or implicitly (see also Prinz, 1983, for a similar distinction between relevance and pertinence as selection criteria). Explicit expectations are occasionally generated and maintained consciously on the basis of conscious considerations or verbal instructions. In addition to occasional explicit expectations, implicit expectations are continuously generated and tested automatically on the basis of knowledge acquired in similar situations. Expectations are viewed here as based on, and subsequently incorporated into the dynamic model of the situation that guides the observers' actions (Neisser, 1976; Rumelhart, 1984).

A division of labor between contingent capture and surprise is of significance for adaptive action. While contingent capture promotes flexible and efficient search on the basis of salient stimulus features that are believed to characterize the target of the search, surprise ensures that unexpected events not sharing features with the target become selected for further processing. Unintended attentional capture could even be seen as a necessary complement to intentional contingent capture.

Are there other positions beside the surprise-attention hypothesis that could explain the results? For example, Theeuwes and colleagues (e.g., Theeuwes, 1992, 1994;

Theeuwes and Burger, 1998; Theeuwes & Godijn, 2001; see also Kim & Cave, 1999) have proposed that irrelevant singletons capture attention in their own right. Theeuwes and Burger (1998) used Wolfe's (1994) Guided Search model as a theoretical underpinning of their position. According to this account, the order in which the display items are serially searched through is determined by both bottom-up and top-down salience. Bottom-up salience of an item increases with featural dissimilarity from other display items, whereas top-down salience increases with the similarity between an item and the target. On the basis of these assumptions it could be argued that in the critical trial of the present experiment, the singleton was salient only by virtue of bottom-up salience, while top-down salience was absent for the singleton. As such, this model could explain attentional capture (or guidance) by a singleton (bottom-up salience) in the absence of a similarity to target features (top-down salience). However, the model has problems immediately explaining the differences in time course, although it might account for this result with additional assumptions, such as that bottom-up salience accumulates over time. On the other hand, some authors (e.g., Kim & Cave, 1999; Theeuwes & Godijn, 2001) have provided arguments and empirical evidence for the hypothesis that singleton capture is very fast, occurring with a latency of less than 100 ms. A singleton-capture hypothesis conceived in this way is evidently incompatible with the present results.

As a last point, the issue of intentionality of capture should be shortly revisited. Intentionality is one of the classical criteria that were thought to distinguish between automatic and voluntary processes (e.g., Posner & Snyder, 1975). Although the concept of automaticity has been revised since then (e.g., Bargh, 1989; Neumann, 1984) and it is now well known that processes such as voluntarily attending to a singleton in visual search can possess both features of voluntary processes (e.g., consciousness), and features of automatic processes (e.g., efficiency), the concepts of consciousness, intentionality, and efficiency can still be considered useful in characterizing mental processes.

For the intentionality criterion, different definitions (and operationalizations) have been proposed. For example, Posner and Snyder (1975) asked whether intentions are necessary for the process to occur, while Jonides (1981) asked whether the process could be voluntarily suppressed (see also Theeuwes & Burger, 1998). For another version, Yantis (1993) defined stimulus-driven (i.e., non-intentional) attentional capture as attentional capture by an attribute that is independent of either the defining attribute of the target (i.e., what distinguishes the target from the distractors) or the reported attribute (e.g., the attribute on which the choice of the response depends). In a reply to Yantis (1993), Folk et al. (1993) disagreed with that definition, stating that attentional capture is unintended if it is contrary to an optimal strategy vis-à-vis the current goals.

The diversity of definitions is possibly due to a conflation of the two concepts of controllability and intentionality proper. According to this view, questions concerning the suppression of attentional shifts to an irrelevant singleton as tested by Jonides (1981) and Theeuwes (1992, 1994; Theeuwes & Burger, 1998), for example, or questions concerning the successes and pitfalls of orienting attention to elements with certain characteristics while ignoring items with other characteristics, as examined by Folk et al. (1992), pertain primarily to the concept of control: To what extent are attentional shifts controllable and where are the limits of control? The original definition of intentionality, as well as the definition proposed by Yantis (1993), pertain to quite a different question: Are intentions really needed for the process to occur? This is also the question addressed in the experiments by Gibson and Jiang (1998), Horstmann (2002, 2004), and the present experiment.

Intentionality and controllability can be seen as corresponding to the necessary and sufficient conditions of processes, respectively. For the intentionality criterion it is questioned whether intentions are necessary for the process to start and run to completion, while for the controllability criterion the question is whether intentions are sufficient to modify or even suppress the process. At the core of the surprise-attention hypothesis as presented here is one assumption concerning the intentionality criterion, but not the controllability criterion: Attentional-capture of a surprising element can occur independently of a previously established intention to attend to the element that happened to be surprising.

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