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Attentional bias in change detection

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Although change detection constitutes an important and pervasive process in our everyday lives, phenomena such as change blindness show that we are quite limited in our ability to notice even large changes in visual scenes. This process is greatly dependent on attention, so change blindness often occurs when attention is diverted from the changing object. This study explores the efficiency of change detection for stimuli that employ our attentional resources in different ways. A flicker paradigm is used to test how top-down and bottom-up attentional biases affect the change detection process and how they interact when jointly present within a task. Our results indicate the influence of top-down attentional effect reflected in the more efficient change detection in conditions where changes occurred in the set of stimuli participants were employing at the time. The effect of bottom-up attentional bias on the efficiency of change detection was not statistically significant.

Key words: change detection, top-down attentional bias, bottom-up attentional bias, attention, visual perception

We live in a constantly changing environment and change detection is important in order to efficiently function in the world that surrounds us. Our sensory organs are biased to register changes in a sense that they stop responding during continuous presentation of a nonvariant stimulus, so it would seem reasonable to assume that we are generally good at this task. This would correspond to our experience of a rich and vivid visual world and an intuitive notion of having detailed visual representations at all times. However, studies related to change detection, a process of apprehending changes in the world around us, have shown that this notion may be somewhat flawed.

Last decade has been marked by an increasing interest in the process of change detection prompted by numerous studies that have provided evidence for observers' unexpected difficulties in noticing even large changes to visual scenes (Simons & Levin, 1997). This inability to detect changes in scenes from one glance to another, also known as "change blindness", was at first taken as evidence of scarce representations of visual scenes and small amount of information being preserved in visual short-term memory (e.g. Rensink, 2000). However, as Simons and Ambinder (2005) argue, this interpretation represents only one possible explanation, because a successful process of change detection needs more than a sufficiently detailed representation of the scene before the change. Therefore, change blindness could occur for other reasons, such as the inability to compare representations of pre- and post-change scenes (e.g. Simons, 2000). One of the most often proposed mechanisms for change blindness states that the post-change display simply masks or overwrites the first picture (Enns & DiLollo, 2000), thus disrupting the representation of the first scene which could have been used as a reference for comparison with the second representation. However, Simons, Chabris, Schnur and Levin (2002) have shown that overwriting cannot entirely account for change blindness because observers that had not detected changes in certain trials of their study were nevertheless able to recognize pre-change stimuli. Thus, it seems likely that, at least for some conditions, change blindness could reflect a failure to compare the two scenes.

Numerous studies have attempted to analyze the process of change detection, the mechanisms that underlie it and the factors that influence it. One element that has been widely acknowledged as important for change detection is attention. One evidence of the importance of attention comes from a study by Rensink, O'Regan and Clark (1997) who have shown, using a flicker task, that observers are better at detecting changes at regions that were rated as more interesting before the experiment. In a similar vein, Kelley, Chun and Chua (2003) have shown that changes to the central elements of the scene are more easily detected than other changes of equal physical salience, while Simons and Levin (1998) noted that change blindness occurs when changes occur unexpectedly and thus remain unattended. Individual characteristics can also be an important factor in change

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detection process, as can be seen from a study conducted by Jones, Jones Smith and Copley (2003), who have shown that social drug users are more likely to detect changes in pictures depicting drugs than non-users. On the other hand, Scholl (2000) has shown that using exogenous cues to draw attention to the location of change can also be efficient in reducing change blindness.

Since change blindness occurs when attention is diverted from the signal, Rensink (2002) proposes that attention is crucial in constructing a limited number of comparisons of relatively complex structures that become basis for change detection. Henderson and Hollingworth (1999) have shown that saccade direction and fixation position play an important role in determining whether changes will be noticed, but, interestingly, O'Regan, Deubel, Clark & Rensink (2000) state that changes may go unnoticed even when the subject looks directly at the location containing a change. Similarly, Williams and Simons (2000) have shown that changes of attended objects can also go unnoticed. In conclusion, the aforementioned findings suggest that the relationship between attention and detection is not symmetrical: although attention is needed for successful detection of changes, it might not be sufficient.

Although attentional involvement may not by itself guarantee successful change detection, nevertheless its relevance cannot be ignored. However, it is important to consider the fact that attention is not a unitary phenomenon. Namely, attention allocation can be guided by two distinct classes of factors, endogenous and exogenous ones (Yantis, 2000). Endogenous or top-down factors include our goals, intentions and internal states, giving the characteristics of the outside world that are compatible with our template a greater probability of being attended. On the other hand, attention can be directed in a stimulus-driven or bottom-up manner. This refers to the situations when the attention is captured by salient features of the environment, even in situations when they are task irrelevant. Turatto and Mazza (2004) suggested that top-down and bottom-up factors act together to create an "activation map", a biased representation of the external world in which each element of the visual field is represented according to its relevance and salience. Therefore, when presented with a visual display we first direct our attention towards the most important or salient elements, which are then followed by other elements, depending on their level of activation. It is not only perception, but also change detection that depends on levels of activation of different elements: changes can be noticed faster when they are associated with high priority items. An item of "high priority" can be an element which is either central to the meaning of the scene or visually distinct (Rensink et al., 1997). In line with this conclusion are the previously mentioned studies which used different types of cues in order to show that both bottom-up (e.g. Scholl, 2000) and top-down (e.g. Kelley et al., 2003) attentional biases are important for successful change detection. In other words, if the change occurs to a salient, clearly visible element of the scene, it will be more easily noticed than if it occurs to some other, less pronounced part of the scene. Also, changes in the scene will be more easily noticed if they occur to an element which is either personally important to the observer (Yaxley & Zwaan, 2005) or necessary for the successful completion of a concurrent task (Triesch, Ballard, Hayhoe, & Sullivan, 2003).

The results of the abovementioned research, while proving that different types of attentional bias may be present concurrently, do not provide us with the method with which to compare or mutually relate their influences. It is hard to speculate what would happen in situations where both top-down and bottom-up attentional bias were present, each pointed in a different direction, so that one of them would facilitate the change direction, while the other would interfere with it. It would be hard to predict which one of these biases would be stronger, how they would interact or jointly affect observer's performance. Thus, the present study was designed in order to address the relationship and the interaction between top-down and bottom-up attentional bias in change detection. We manipulated these two types of attentional bias and addressed both their individual influences and the effects of their interaction.

METHOD

Participants

A total of 23 participants, 19-22 years old psychology students with normal or corrected vision, participated in the study and received credits for their participation.

Procedure

Experiment was designed using SuperLab and run on a PC computer with a 640 × 350 monitor resolution. The participants were seated 40 cm in front of the computer and presented with sets of stimuli used in a flicker paradigm. Each stimulus trial included an alternating presentation of two stimulus pictures which both lasted for 400 ms and were separated by a 200 ms interstimulus interval, during which a blank screen (white mask) was presented. Each picture included two distinct 6-digit sets of numbers placed one on top of the other and separated by a thin gray line. The numbers were presented on a white background. The two alternating pictures in "change trials" differed in the identity of one of the numbers (digits) presented in either set while in "no-change trials" there was no difference between the two pictures. The alternations of initial and changed stimulus were repeated 5 times, so that each trial throughout the experiment contained the presentation of 10 individual pictures. The alternation of the stimuli was not stopped in cases when the participant noticed the change, but continued until

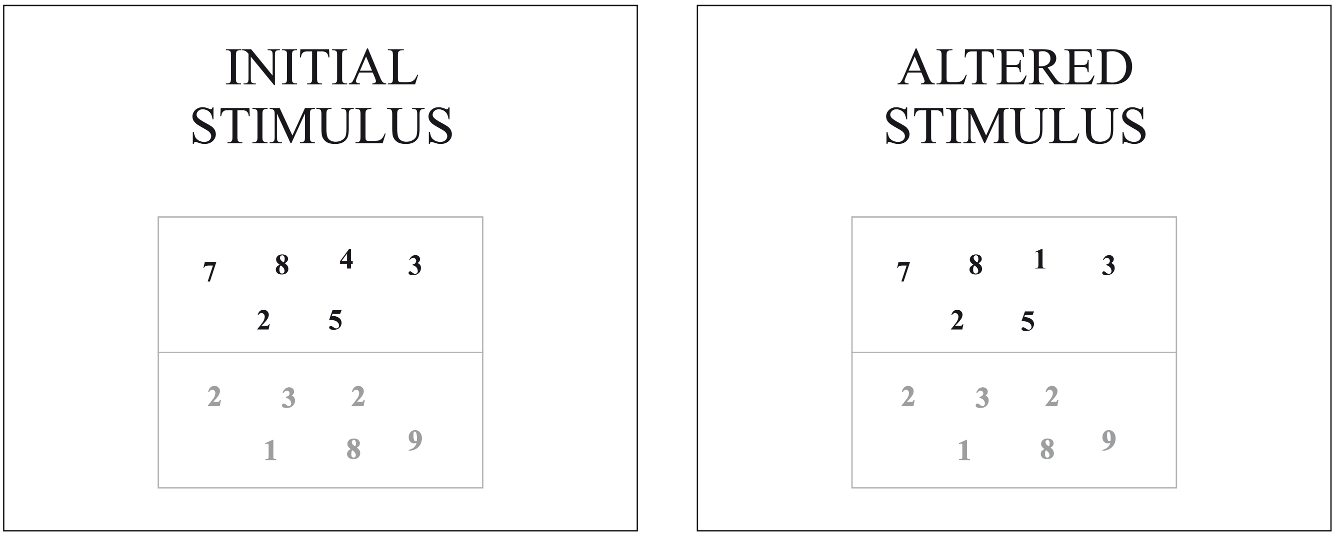

Figure 1. An example of stimulus display (darker color represents red and lighter represents gray from the original display)

the end of the trial. The example of the stimulus used is presented in Figure 1.

In order to manipulate bottom-up attentional bias, the color of the numbers presented in the picture was alternated during the trials. Color was chosen because it represents one of the stimulus features which can be used to efficiently guide attention (Wolfe & Horowitz, 2004). In the no-bias condition both sets of numbers were gray, while in the bottom-up biased conditions one of the sets was red. In order to manipulate top-down attentional bias, the participants were given instructions to direct their attention to a particular part of the picture (Hoffman, 1998) and this was accomplished by presenting a small black fixation cross on the screen before the trial. The cross was used to indicate where the participants should direct their attention during the trial: on the whole picture (cross presented in the middle of the screen), on the upper (cross presented in the center of upper part of the screen) or lower set of numbers (cross presented in the center of the lower part of the screen). Thus, focusing participants' attention at the whole picture created no specific bias while the instructions to direct attention either on the upper or the lower set did. The exact duration of the fixation cross' appearance on the monitor was set by participants: after the end of each trial a fixation cross would appear to instruct them about the upcoming trial. The trial started after the participants pressed a space bar.

Participants' task was to detect the change and quickly respond by pressing the marked keyboard key. If the trial contained no change participants were instructed not to respond until the end of the trial. The task of responding only to change trials was chosen because in no-change trials the participants would not be able to correctly identify images as "same" until the trial was already finished.

A within-subject design was used, with a total of 54 change trials (6 per experimental condition) and the same number of no-change trials, which were presented to each of the participants in three blocks of measurement. Each of the created displays (number arrangements within the picture) was presented three times during the experiment, with different instructions given to the participants (directing their attention to the whole picture, to the lower or upper set of numbers). Changes in the stimuli could occur in either set, upper or lower one, regardless of the color of the stimuli or the focus of attention, as directed by the instructions. Trials were presented quasi-randomly within each of the blocks (each block contained all types of trials) and were interleaved with no-change trials which served as a control of the accuracy of participants' reactions. The order of blocks was rotated between participants. Participants were given a practice period before the experiment.

Trials throughout the experiment differed in the presence of top-down and bottom-up attentional bias, so they could either include: a) no attentional bias (both sets of numbers gray and instruction to direct attention to the whole picture); b) only top-down bias (both sets of numbers gray and instruction to direct attention to one set of numbers); c) only bottom-up bias (one red and one gray set of numbers and instruction to direct attention to the whole picture) or d) both top-down and bottom-up bias (one red and one gray set of numbers and instruction to direct attention to one set of numbers), with biases being either congruent (instruction to direct attention to red numbers) or incongruent (instruction to direct attention to gray numbers). In all change-trials in no-bias situations changes could occur in either set of numbers with equal probability. In situations where attentional bias was present, changes could occur either in the attended or the unattended set with equal probability (50%). The layout of the display, namely the distribution of numbers on the display, the position of the highlighted set of numbers and of the set of numbers in which the change takes place were randomly chosen and had equal probability of occurrence. Overall there were nine experimental situations present within the experiment:

- baseline/neutral situation: two gray sets of numbers presented; participants direct attention to both sets; changes could occur in either set
- bottom-up facilitation: one set of numbers red, the other gray; participants directed attention to both sets; changes occurred in the highlighted (red) set of numbers
- bottom-up interference: one set of numbers red, the other gray; participants directed attention to both sets; changes occurred in the non-highlighted (gray) set of numbers
- top-down facilitation: two gray sets of numbers present; changes occurred in the set of numbers participants were instructed to attend
- top-down interference: two gray sets of numbers present; changes occurred in the set of numbers participants were instructed not to attend
- joint top-down and bottom-up facilitation: one set of numbers red, the other gray; changes occurred in the red set of numbers that the participants were instructed to attend
- top-down facilitation and bottom-up interference: one set of numbers red, the other gray; changes occurred in the gray set of numbers participants were instructed to attend
- top-down interference and bottom-up facilitation: one set of numbers red, the other gray; changes occurred in the red set of numbers while participants were instructed to attend to the gray
- joint top-down and bottom-up interference: one set of numbers red, the other gray; changes occurred in the gray set of numbers while participants were instructed to attend to the red one.

RESULTS

The accuracy and the occurrence of change detection, that is, the number of scene alternations identified by the participants, were recorded. All participants had 90% or higher accuracy rates in no-change trials (the number of false alarms was under 10%). The distribution of reactions in change trials in all experimental situations were not statistically different from normal [Kolmogorov-Smirnov tests were not significant (p>.05) in all situations], so parametric statistics were used in all of the remaining analyses.

The efficiency or success of change detection across different situations was measured by using proportion of trials in which the participants correctly detected the presented change (possible range: 0-1). The average proportion of perceived changes for each experimental situation (Figure 2) was calculated and further analyzed in order to see if the efficiency of change detection differed under different attentional demands.

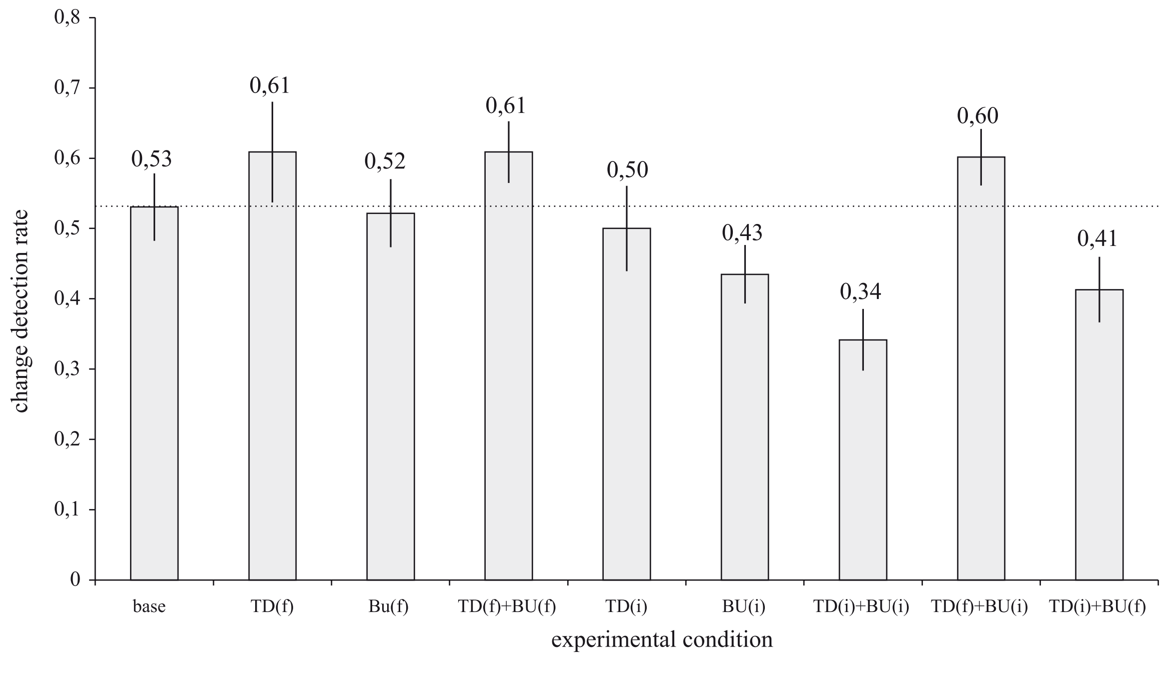

Figure 2. The efficiency of change detection (percentage of correct change detections) in different experimental conditions

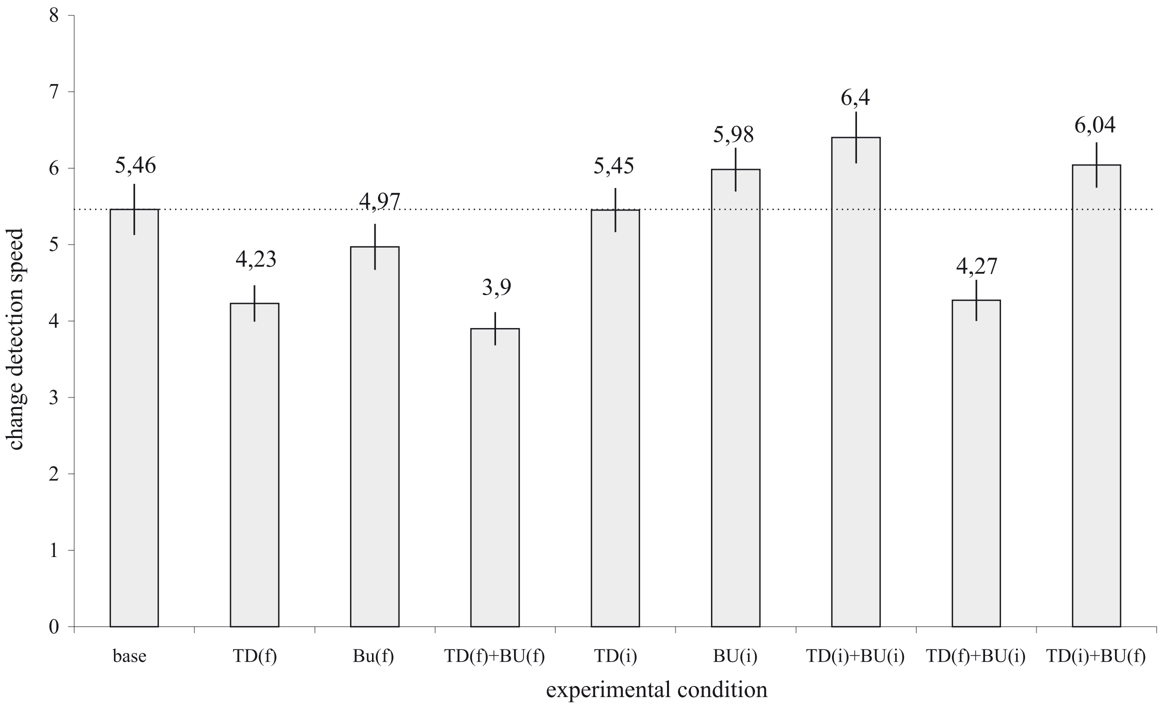

Figure 3. The speed of change detection (number of alternations) in different experimental conditions

Legend

base	baseline/neutral situation
TD(f)	top-down facilitation situation
BU(f)	bottom-up facilitation situation
TD(f)+BU(f)	top-down and bottom-up facilitation situation
TD(i)	top-down interference situation
BU(i)	bottom-up interference situation
TD(i)+BU(i)	top-down and bottom-up interference situation
TD(f)+BU(i)	top-down facilitation and bottom-up interference situation
TD(i)+BU(f)	top-down interference and bottom-up facilitation situation

Repeated measures two-way ANOVA were used in order to test the influence of two factors: top-down attentional bias (3 levels: no top-down, top-down facilitation and top-down interference) and bottom-up attentional bias (3 levels: no bottom-up, bottom-up facilitation and bottom-up interference). Results showed a significant main effect of top-down attentional bias (F (2, 88) = 10.59, p<.01; effect size: partial eta squared .325), while post-hoc Bonferroni pairwise comparison revealed significant differences between the top-down attentional facilitation conditions, when compared to the top-down interference (p<.01) and conditions without an top-down attentional bias (p<.05). The main effect of bottom-up bias (F(2, 88) = 2.04, p>.05) and the interaction (F (4, 88) = .92, p>.05) did not reach statistical significance. The differences between particular experimental situations were tested using paired t-tests (Table 1).

In addition to success of change detection which was used as the main index of detection efficiency, information related to the speed of change detection was recorded. We identified trials in which changes were successfully detected by each respondent, and registered when (at which alternation) during the trial this occurred. The average number of alternations before the response was calculated for each condition (taking into account only responses from participants who made a correct detection) and the results are shown in Figure 3. Since the obtained results related to this variable showed a trend highly comparable to that of success of change detection, this measure provided little additional information and was not further statistically analyzed.

DISCUSSION

The present experiment addressed the efficiency of change detection for stimuli that employ our attentional resources in different ways: on the one hand, those that the participants attend in contrast to those which they ignore (top-down attentional bias) and, on the other, those which by the virtue of their salience create a bottom-up attentional bias in contrast to those which are not accentuated (bottom-up attentional bias). The obtained results reveal a statistically significant main effect of top-down attentional bias. Instructing participants to direct attention on one set of numbers and introducing a change in the attended set created a facilitation effect, as reflected by more accurate change detection process in top-down facilitation conditions, when compared to baseline and top-down interference conditions. The influence of manipulating bottom-up attentional bias and the interaction between the two variables was not statistically significant.

Looking only at this level, the obtained results seem to show a rather simple pattern. However, this is somewhat misleading, because the present study taps into two different issues, and this was only partly intended. One of them, namely the relation between the two types of attentional biases, represents the main focus and is, therefore, primarily discussed. However, in order to account for different potential directions of influences of these two factors, the design of this experiment included both interfering and facilitating types of effects. The comparison between the relative strengths of these effects within each attentional bias is beyond the scope of this paper, but this issue by itself

Table 1
Comparisons (results of paired t-tests) of success of change detection between pairs of experimental situations

	Success of change detection		
Condition	*t*	*df*	*p*
baseline vs. bottom-up facilitation	0.14	22	.89
baseline vs. bottom-up interference	1.50	22	.15
baseline vs. top-down facilitation	-1.18	22	.25
baseline vs. top-down interference	0.45	22	.66
baseline vs. top-down and bottom-up facilitation	-1.31	22	.20
baseline vs. top-down facilitation and bottom-up interference	-1.32	22	.20
baseline vs. bottom-up facilitation and top-down interference	1.68	22	.11
baseline vs. bottom-up and top-down interference	2.73	22	.01*
bottom-up facilitation vs. bottom-up interference	2.15	22	.04*
top-down facilitation vs. top-down interference	1.18	22	.25
bottom-up facilitation vs. top-down and bottom-up facilitation	1.37	22	.19
top-down facilitation vs. top-down and bottom-up facilitation	0.0002	22	1.0
bottom-up interference vs. bottom-up and top-down interference	-2.37	22	.3
top-down interference vs. bottom-up and top-down interference	-1.74	22	.94
bottom-up facilitation vs. bottom-up facilitation and top-down interference	1.76	22	.09
top-down facilitation vs. top-down facilitation and bottom-up interference	0.09	22	.93
top-down facilitation vs. bottom-up facilitation	1.14	22	.27
top-down facilitation and bottom-up interference vs. bottom-up facilitation and top-down interference	2.80	22	.01*
top-down and bottom-up facilitation vs. top-down facilitation and bottom-up interference	0.13	22	.89
top-down and bottom-up facilitation vs. bottom-up facilitation and top-down interference	3.49	22	.002**
top-down and bottom-up facilitation vs. bottom-up and top-down interference	4.42	22	.001**
bottom-up and top-down interference vs. top-down facilitation and bottom-up interference	-4.66	22	.001**
bottom-up and top-down interference vs. bottom-up facilitation and top-down interference	-1.51	22	.15

Note. *p<.05; **p<.01

could be interesting to address within further studies. If well manipulated, it could provide a way to test potential implications of the provisory conclusion from the *Introduction* which stated that attention may be needed, but not sufficient for change detection. In hope that the present study might help in formulating the questions, pairways comparisons between individual experimental conditions are presented in Table 1.

The efficiency of change detection within the present study was evaluated based on the proportion of trials in which participants correctly identified the change. In addition, we also recorded data reflecting the speed of change detection which were not statistically analyzed in the same degree as the principal measure of change detection success. More specifically, since each trial included an alternation of 10 pictures it was possible to record the number of alternations which were needed in order to notice the change in conditions in which this actually occurred. Based on the number of alternations, it would also be possible to calculate respective reaction times which would serve as a more sensitive measure of detection speed. Since the principal question of this study was a more "general" one, we believed it would be more appropriate to base the interpretations of the obtained results on one, somewhat more robust measure of change detection efficiency, but nevertheless present the descriptive values of the speed of change detection for each condition for the interested reader. Keeping in mind that the lack of statistical power prevents any strong interpretations or claims, it might be interesting to notice that, in principle, more accurate change detection process was principally coupled with somewhat faster reactions. Values reflecting detection speed indicate a trend which is comparable to the one reflected in the success of change detection, based on which it is possible to speculate that the accuracy of change detection does not come at the expense of speed. If the change was not noticeable to the participants, adding more alternations did not lead to an improvement of performance.

Additionally, it needs to be stated that the exact interpretation regarding the meaning and the relationship between these two measures represents somewhat of an empirical question. They probably reflect rather different aspects of the change detection process and definitely differ in their sensitivity. Since the present study included quite a lot of experimental conditions, one of these measures was used as a principal indicator of change detection efficiency. We chose to focus only on this one because the alternative of adding both measures, especially given rather converging interpretations which could be based on them, did not have significant additional informative value. It would be very interesting to try and address the process of change detection with more scrutiny and better characterize different alternative measures which can be used for describing its efficiency. This should, however, be done in a more systematic fashion than the present study allowed.

Overall, the results obtained within this study are somewhat complex and cannot be interpreted in a simple and unequivocal manner, and this might be attributed to the choice of paradigm as well as the exact procedure used in the experiment. Therefore, they should not be taken as definite indicators of the relationship between different types of attentional biases and their role in change detection because a different operationalization of stimuli and procedure could have resulted in a different pattern of results.

When interpreting the results one could, on one hand, speculate about a generally stronger influence of top-down attentional bias in change detection. However, it is important to note that results could partially reflect the nature of used stimuli, namely numbers which were somewhat arbitrarily chosen. As abstract cognitive concepts, numbers may require additional cognitive processing and could generally be under more top-down influences when compared to some other types of stimuli. One salient bottom-up feature of the numbers is their shape which presumably activates recognition (top-down process) which could interfere with potential influences of other bottom-up features such as color. Therefore, the obtained results may not be easily extended to other types of visual materials.

Additional problem with the manipulation of the bottom-up attentional bias refers to the fact that in our procedure we made one set of numbers more salient using color as a distinctive attribute, basing this decision on relevant literature data (Wolfe & Horowitz, 2004) as well as some of our preliminary measurements conducted while preparing this experiment. However, since we did not accentuate only one (changing) digit, but the whole set of digits (equivalent to top-down attentional bias) we are probably underestimating "the power" of bottom-up attentional bias in improving the success of change detection. It would be of interest to manipulate this bias in a more focused manner, specially using different types of stimulus materials.

The obtained results could also partly reflect the nature of the used design. In this experiment, a within-subject experimental design in which all participants underwent all experimental conditions was used. Their knowledge about the existence of different conditions could have influenced their general strategies during responding. This would primarily be reflected in the top-down attentional bias which is directly dependent on participants' "collaboration". In contrast, in the bottom-up conditions more salient stimuli should, in principle, attract participants' attention regardless of their intentions.

Since the participants knew that the changes could occur anywhere in the two sets of numbers in all conditions, it is possible that, especially during the top-down manipulation they focused on more than the designated part of the screen. In this case, the strength of the top-down attentional factor would be underestimated in the obtained findings. First of all, participants' overall attentional focus would be more spread to both sets of numbers which could have lead to less facilitation in situations where the changes occurred in the attended set. Secondly, an improvement in performance would be expected with respect to the top-down interference condition. In the extreme case where the participants failed to follow the instruction, same performance would be expected in the baseline and conditions where only top-down bias was presented. In the present experiment top-down manipulation had an effect which indicates that the participants were following the instruction. However, it is not possible to exclude the fact that the knowledge of the presence of all conditions influenced their strategy.

Similarly, participants were aware that changes could occur in either one of the sets, regardless of whether it was accentuated/attended or not. On one hand, this is obviously sub-optimal because they principally knew that following the instruction in the top-down condition occasionally meant that it was more unlikely for them to solve the task. However, they were not aware of the probability of these cases. Although this was not ideal, the alternative of not explaining or explicitly deceiving the participants about this aspect of the task was not chosen because it was considered to be even more problematic. Since the participants' task was such that they had to be explicitly aware of the change in order to correctly respond to it, deceiving participants would have only worked if it was possible to guarantee that they would never notice the change in the interference conditions. Once they did, it would have become obvious that the instruction was false. This would probably occur at different points in time for different participants and would trigger different "coping" strategies, leading to an increase in variance of their results. This was avoided by presenting all participants with equivalent instructions and stressing the importance of following them.

The choice of stimuli, as well as the overall paradigm used in this experiment, allow only indirect comparison of the influence of different types of attentional biases. This question would be an interesting one to address in similar experiments, especially because some authors indicate that bottom-up attentional bias can only exist if an adequate mental set is present, suggesting that it can be overridden by top-down attentional bias (Folk, Remington & Johnston, 1993; Ruz & Lupiáñez, 2002). Our results are far from being conclusive regarding the relationship between these biases, so additional experiments are needed in which different stimuli and operationalizations of the manipulated biases would be used in order to make any more concrete conclusions. More rigorous probing of the nature of their interactions could be accomplished by balancing the relative strength of the two biases somewhat more systematically and across different types of materials.

CONCLUSION

The obtained results indicate the importance of top-down attentional bias in detecting changes occurring at presented visual scenes. However, although the effect of bottom-up bias was not significant, the obtained pattern of results should be interpreted keeping in mind the operationalization of attentional biases. The obtained findings need to be addressed and verified through different paradigms and tasks within studies addressing mechanisms and neural bases of attentional biases in change detection.

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