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Markus Grüner, BSc

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Cueing Effects of Achromatic Color Cues During Search for Onset Targets

Markus Grüner

University of Vienna

Student no.: 0953690

Abstract

Despite extensive research it is not yet entirely understood how the orientation of attention is influenced by top-down and bottom-up mechanisms. Here we investigated whether achromatic color (light and dark) can be used for top-down control of attention during search for onset targets. In two experiments participants ($N = 32$) searched for light (Experiment 1) or dark (Experiment 2) abrupt onset targets, preceded by supraliminal presented light or dark achromatic color singleton cues. According to the contingent capture of attention hypothesis only cues with task-relevant features capture attention, while cues with task-irrelevant features do not. We found that only cues with the same achromatic color as the target captured attention, whereas cues with the contrary achromatic color than the target did not. This confirms the contingent capture of attention hypothesis and indicates that achromatic color can be used as a feature for top-down control of attention during search for abrupt onset targets. We discuss the results relating to the scope and limits of top-down influences on control mechanisms of attention and the interaction with bottom-up influences.

Keywords: cueing, contingent capture of attention, achromatic color, onset target, singleton cue

Zusammenfassung

Trotz intensiver Forschung ist noch nicht völlig klar, wie die Verlagerung von Aufmerksamkeit von top-down und bottom-up Faktoren beeinflusst wird. In dieser Arbeit untersuchen wir, ob achromatische Farbe (hell und dunkel) zur top-down Kontrolle von Aufmerksamkeit verwendet werden kann. In zwei Experimenten suchten Versuchspersonen ($N = 32$) nach hellen (Experiment 1) oder dunklen (Experiment 2) plötzlich auftauchenden Zielreizen. Gemäß der Hypothese der zielreizabhängigen Verlagerung von Aufmerksamkeit wird die Aufmerksamkeit nur von Hinweisreizen angezogen, die aufgabenrelevante Merkmale besitzen, während Hinweisreize mit aufgabenirrelevanten Merkmalen die Aufmerksamkeit nicht anziehen. Es zeigte sich, dass nur Hinweisreize mit der gleichen achromatischen Farbe wie der Zielreiz die Aufmerksamkeit anzogen, nicht jedoch Hinweisreize mit der konträren achromatischen Farbe. Das bestätigt die Hypothese der zielreizabhängigen Verlagerung von Aufmerksamkeit und lässt darauf schließen, dass achromatische Farbe als Merkmal für top-down Kontrolle von Aufmerksamkeit verwendet werden kann, wenn nach plötzlich auftauchenden Zielreizen gesucht wird. Wir diskutieren die Ergebnisse im Bezug auf den Geltungsbereich und die Grenzen von top-down Einflüssen auf Kontrollmechanismen von Aufmerksamkeit und die Interaktion mit bottom-up Einflüssen.

Schlüsselwörter: Hinweisreize, zielreizabhängige Verlagerung von Aufmerksamkeit, achromatische Farbe, plötzlich auftauchender Zielreiz, Singleton Hinweisreiz

Contents

For every organism processing information is crucial for survival. But the amount of information that can be processed is limited by two factors: At first there is a fundamental limitation, because the sensory organs are specialized in only a certain kind of information. For instance, humans are only able to process a small section of the electromagnetic spectrum. Different wavelengths within this spectrum are perceived as different colors. The second constraint concerns the amount of information which can be processed at the same time. The sensory organs provide a huge amount of information about the environment every moment of time. But due to the limited resources of the brain not every information can be processed far enough to affect behavior. Aside from that the amount of possible behaviors is restricted by the body or organs of an organism, for instance, we have only two arms and two eyes to move (cf. Allport, 1987). These limitations are the reason why perception has to be selective and this selectivity is called attention (Carrasco, 2011).

Scientists have been trying to unravel the mechanisms of attention since the beginning of psychology as a scientific field in the late 19th century. James (1890) described attention as being either active and voluntary or passive, involuntary and effortless (p. 416). The latter form of attention is also called automatic or bottom-up while active and voluntary attention is referred to as controlled or top-down (e. g. Theeuwes, 2012).

Helmholtz (1894) described an example of controlled attention when he found out that attention can be voluntary oriented without eye movements. Due to the so called covert orientation of attention he reported a better perception at the location where he oriented his attention (cf. Posner, 1980).

Jonides (1981) systematically investigated automatic orienting of attention by comparing central and peripheral cues. The cues either indicated the correct position of a target or an incorrect position and as expected the cues elicited shorter reaction times (RTs) when they indicated a correct target position (valid cue) compared to indicating an incorrect target position (invalid cue). This benefit was attributed to capture of attention by the cue, which resulted in preferred processing at the cued position. Jonides (1981) further concluded that peripheral cues captured attention in an automatic way, because the benefit of valid peripheral cues was independent of cognitive load, peripheral cues were hard to ignore, even when the participants were instructed to do so and peripheral cues captured attention independent of the expected frequency of occurrence (cf. Shiffrin & Schneider, 1977).

The controlled and voluntary orientation of attention is a form of top-down influence, because it happens intentionally and not solely dependent on external stimuli. In contrast, the automatic and involuntary orientation of attention seemed to be based on external stimuli, for example, peripheral cues (Jonides, 1981) or abrupt onset cues (Jonides & Yantis, 1988) and therefore stimulus-driven factors are considered as bottom-up influence. Both factors influence attention at the same time, which becomes obvious in the light of visual search experiments. In such experiments participants search for a predefined target (top-down factors) among simultaneously presented nontarget stimuli, so called distractors (bottom-up factors). In their theory of search Duncan and Humphreys (1989) emphasized the similarity between target and distractors as crucial factor for search efficiency and explicitly pointed out that it is not the similarity between a distractor and a target in the actual search display (which would be a bottom-up factor) but the similarity between a distractor and the internal representation of possible targets (a top-down factor): "We have considered not similarities between one stimulus and another within an actual array, but rather the similarity of each nontarget to any possible target." (Duncan & Humphreys, 1989, p. 447)

But top-down and bottom-up factors do not only influence attention simultaneously, they interact with each other as well. In a seminal work Folk, Remington, and Johnston (1992) showed that cues with a target-defining feature captured attention in an involuntary way, whereas cues without target-defining features were successfully ignored. To test their hypothesis of *contingent capture of attention* they used targets and cues with two different features: an abrupt onset feature and a singleton color feature. The targets always consisted of "X" or "=" and appeared in one of four placeholder in the onset condition. In the color singleton condition the target was a red target among three white targets. The cues consisted of four small dots surrounding each placeholder and were either white onset cues (dots around one placeholder) or singleton color cues (red dots around one placeholder together with white dots around each ot the other three placeholders). During blocks of trials the feature of the target (onset or singleton feature) did not change, whereas the cue was randomly a onset cue or a color singleton cue (Folk et al., 1992, experiment 3). Participants were asked to report the target identity via key press and were faster when a cue with the same feature as the target preceded at the same position (valid trial) compared to conditions were a cue with target-defining feature preceded at a different position (invalid trial). The faster RTs in valid compared to invalid trials is called *cueing effect* and attributed to the capture of attention by the feature-matching cue. The key finding of Folk et al. (1992) was that cues without a target-defining feature did not capture attention, which contradicts the notion that abrupt onset cues always capture attention, independent of top-down processes (Jonides & Yantis, 1988, e. g.). Furthermore these results showed that a top-down setting can elicit involuntary, automatic and therefore hard to ignore orientation of attention (cf. Theeuwes, 2012) when a cue matches the top-down setting of attention. As a consequence, automatic orientation of attention is not always due to bottom-up factors and possible top-down influence should be considered as explanation (Theeuwes, 1992; Bacon & Egeth, 1994; Theeuwes, 2004; Leber & Egeth, 2006).

Folk et al. (1992) tested two different features for their use as top-down control setting of attention: abrupt onset and singleton feature. Their experiments did not allow conclusions about a possible influence of color as a feature for top-down control of attention, because onset cues and targets were always white and singleton cues and targets always red. The present study aims to answers the question whether achromatic color can be used as a feature for a top-down control of attention during search for onset targets.

Some studies suggested color as a feature for top-down control of attention, for instance, Folk and Remington (1998) showed that a specific color can be used for top-down control of attention during search for singleton color targets. When their participants searched for red or green singleton targets, only singleton cues with the same color captured attention. Critically, specific colors were only used as top-down control when a feature search mode was used to identify the target (Folk & Remington, 1998).

Folk and Remington (1998) used target displays that forced participants to adopt a feature search mode in order to find the target. Therefore the effect of color during search for onset targets remained unclear, but nevertheless Folk and Remington (1998) showed that a specific color can possibly used for top-down control of attention.

Ansorge and Heumann (2003) investigated the effect of color during search for onset targets and found that onset cues with a similar color than the target elicited higher cueing effects compared to the onset cues with a dissimilar color. The cueing effect elicited by dissimilar color cues did not vanish, which indicated that the participants used both, the onset feature and color as top-down control of attention (see also Ansorge & Heumann, 2004). Because the cues and the targets used by Ansorge and Heumann (2003) were onsets, it remained unclear whether cue color alone could be used as a feature for top-down control of attention during search for onset targets.

This study aims to fill this gap and to find out whether color can be used as a feature for top-down control. We therefore used only onset targets and only color singleton cues. Without onset cues a cueing effect can be attributed to the effect of a top-down control setting for color. To avoid confounding of different luminance contrasts between stimuli and background when using chromatic colors we used achromatic colors (light and dark) on gray background. Therefore the luminance contrasts of our cues and targets to the background were the same.

By using light or dark onset targets preceded by light or dark singleton cues, the cue could be either matching (light cue precedes light target and vice versa) or nonmatching (dark cue precedes light target and vice versa). Similar to the design used by Folk et al. (1992) the cues and the targets appeared randomly in one of four placeholders and were not informative regarding the target identity. In 25 % of the trials the cue appeared at the same position as the target (valid trial) and in 75 % of the trials the cue appeared at a different position as the target (invalid trial). As a consequence, there is no incentive to voluntarily use the cue.

If the achromatic color of the target is used for top-down control of attention we expect cueing effects to occur only in matching trials. If any pop-out feature—as present in all singleton cues, irrespective of color—captures attention, cueing effects would occur in all valid trials, even in trials where a nonmatching cue preceded the target. This would indicate that participants used a singleton detection mode (Bacon & Egeth, 1994; Leber & Egeth, 2006) to search for the target. If participants only use the onset feature for top-down control of attention, neither matching nor nonmatching cues would elicit a cueing effect, because all cues were singleton cues without an onset feature.

We used two experiments which differed only in the achromatic color of the targets and placeholders. In Experiment 1 participants searched for dark targets whereas the placeholders were light. In Experiment 2 it was the opposite, that is, the targets were light and the placeholders dark. Except for this difference both experiments were exactly the same.

Method

Participants

Sixteen participants (11 females, five males, 19 to 56 years, $M_{age} = 23.56$ years, $SD_{age} = 8.82$, $Mdn_{age} = 21$ years) participated in Experiment 1 and in Experiment 2 sixteen students (nine females, seven males, 19 to 33 years, $M_{age} = 23.69$ years, $SD_{age} = 3.59$, $Mdn_{age} = 23$ years) participated. They were mostly students at the University of Vienna and received course credit for participation. All participants had normal or corrected-to-normal vision and informed consent was obtained. After the experiment all participants were debriefed.

Apparatus

For both experiments participants were seated at a distance of 57 cm in front of an 19-inch LCD monitor (Acer B 193) with a resolution of 1 280 × 1 024 pixels (aspect ration of 4:3) and a vertical refresh rate of 75 Hz. Chin rests were used to stabilize the head position and keep the distance between head and monitor constant.

The participants responded via pressing a key on a standard keyboard. MATLAB 7.7.0 (MathWorks Inc., Natick, MA, USA) and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) were used to control the experiments.

Stimuli

In both experiments light (137.7 cd/m²; –7.8/–28.4) and dark (13.3 cd/m²; –1.8/–9.1) stimuli were used against a gray background (75.5 cd/m²; –5.3/–18.8). Therefore stimuli had the same Weber contrast (± 0.82) against the gray background.

In Experiment 1 the search display consisted of a light central fixation point (0.5°) surrounded by four light, square-shaped placeholders (1.5° × 1.5°). The placeholder were centrally aligned above, below, left, and right from the central fixation point. The distance between the center of the placeholders and the central fixation point was 5.0°. The target in Experiment 1 was a dark “X” or “=” and appeared in one of the four placeholders.

The cues consisted of four dark or light dots (0.25°) surrounding each of the four placeholders. The dots appeared at all four placeholder at the same time and were either dark around one placeholder and light around each of the other three placeholders (referred to as dark singleton cue) or light around one placeholder and dark around each of the other three placeholders (referred to as light singleton cue).

In Experiment 2 the targets were always light and the central fixation point as well as the placeholders were dark. Otherwise all stimuli were exactly the same. Figure 1 on page 15 shows the stimuli and procedure of Experiment 1 and 2.

Procedure

A trial started with the fixations display (600 ms) followed by the cueing display which was presented 50 ms. After displaying the cues the fixation display followed for 100 ms before the target was presented for 50 ms. The participants had to identify the target (“X” or “=”) and report the identity as fast and accurately as possible via pressing a response key on a standard keyboard. Half of the participants were instructed to press “F” with their left index finger when they saw an “X” and “J” with their right index finger when they saw an “=”. For the other half of the participants the mapping between stimulus identity and response key was reversed.

After the target was presented a blank screen followed until the participants pressed a response key. The next trial started immediately after the response key was released. We measured the RT as the time interval between onset of the target and the keypress to the nearest millisecond. If the participant did not press a response key within 1 550 ms after onset of the target the trial was counted as an error trial and the participant received visual feedback (“schneller reagieren” [“react faster”]).

The targets appeared equally often in each of the four placeholder and were randomly “X”

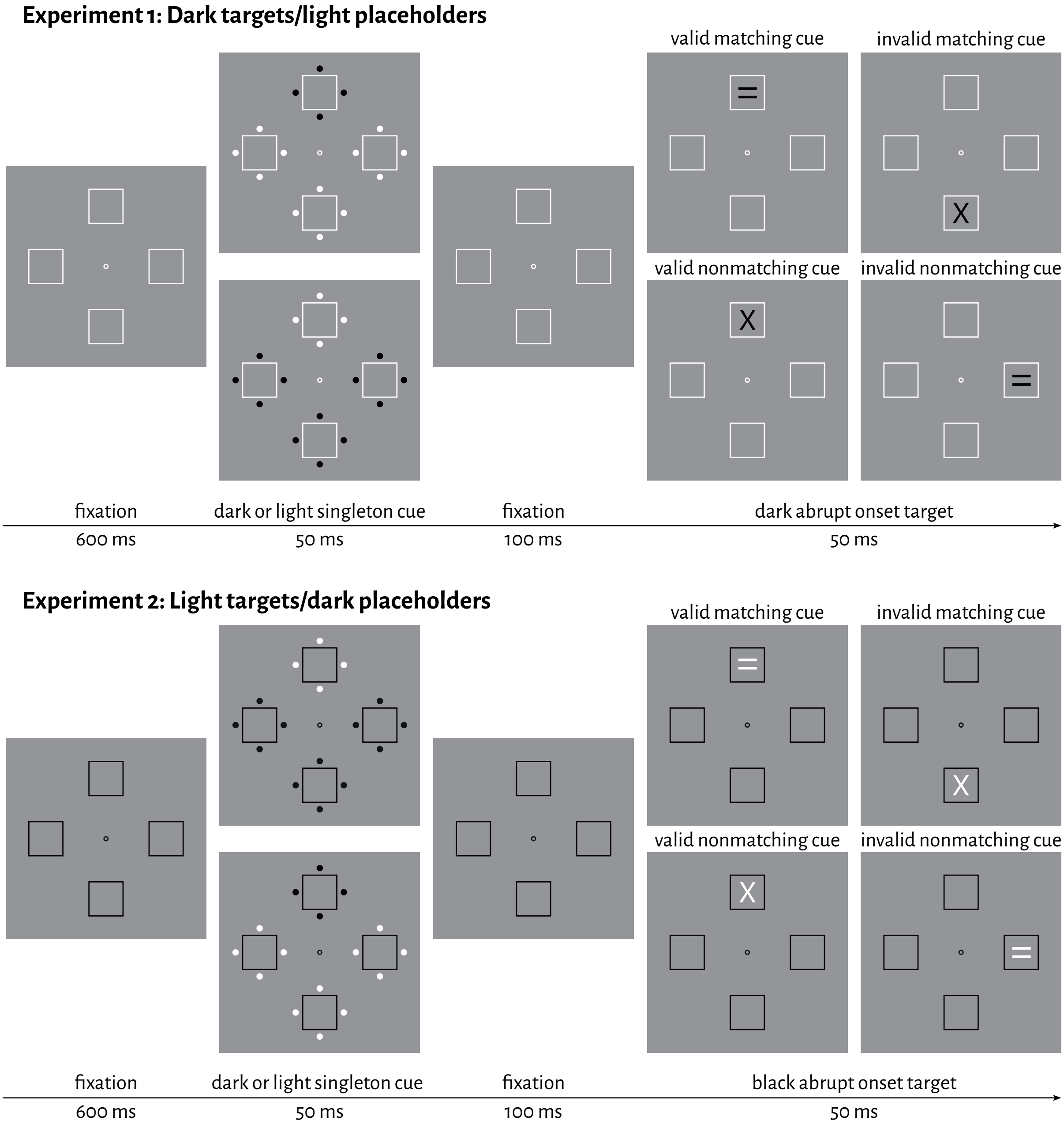

Figure 1. Stimuli and procedure of Experiment 1 (above) and Experiment 2 (below). Participants had to report the identity of the target. The cues were equally often either dark or light singleton cues appearing randomly at one of the placeholders. The target was always dark (Experiment 1) or light (Experiment 2) and never changed their achromatic color. The identity as well as the position of the target were randomly assigned resulting in four different condition depicted on the right sight. The drawn displays are not true to scale.

or "=". The cues also appeared equally often at one of the placeholder positions, resulting in 25 % valid and 75 % invalid trials and four within-subject-conditions: (a) *valid-matching*: The achromatic color of cue and target were the same and the position of cue and target were the same (b) *invalid-matching*: The achromatic color of cue and target were different but the position of cue and target were the same (c) *valid-nonmatching*: The achromatic color of cue and target were different but the position of cue and target were the same (d) *invalid-nonmatching*: The achromatic color of cue and target were different and the position of cue and target were different.

Each session started with unrecorded practice trials. Only during the practice trials participants got feedback for their answers (*richtig!* [*correct!*] or *falsch!* [*incorrect!*]).

Error trials were repeated at the end of the session resulting in a constant number of correct answered trials despite different error rates. The participants were not instructed about this. The experiments were held in a dimly lit room with only a small light behind the monitor. One session lasted about one hour with three breaks in between.

Results

We excluded RTs below 150 ms and error trials before analysis, which resulted in 6.93 % excluded trials in Experiment 1 and 6.50 % excluded trials in Experiment 2. Cueing effects were computed by subtracting the correct mean RTs in valid trials from the correct mean RTs in invalid trials.

For further analysis we used a 2 $\times$ 2 repeated measurements analysis of variance (ANOVA) with cue color (match vs. nonmatch) and cue position (valid vs. invalid) as within-subject variables. Error rates were analyzed using loglinear analysis and chi-square tests.

Reaction Times – Cueing Effects

Experiment 1. When a cue with the same achromatic color as the target precedes the target at the same position (valid-match condition) RTs (in milliseconds) were faster ($M = 393$, $SE = 2.10$) than when the target appeared at a different position (invalid-match condition, $M = 423$, $SE = 1.25$). This difference represents a significant cueing effect of 30 ms,

$t(5412.7) = -12.15$, $p < .001$, which is a small effect size, Cohen's $d = 0.25$ according to Cohen (1988).

When the cue had a different achromatic color as the target, we found a reversed cueing effect, that is RTs were slower when such a nonmatching cue preceded the target at the same position (valid-nonmatching condition, $M = 417$, $SE = 2.11$) than at a different position (invalid-nonmatching condition, $M = 408$, $SE = 1{,}24$). The reversed cueing effect of –9 ms is significant, $t(5305.2) = 3.47$, $p < .001$, although the effect size is extremely small ($d = 0.07$).

Experiment 2. Experiment 2 yielded similar results. RTs in the valid-match condition were faster ($M = 387$, $SE = 1.99$) than in the invalid-match condition ($M = 423$, $SE = 1.19$), resulting in a significant cueing effect of 36 ms, which represents a small to medium effect size ($t(5430.5) = -15.50$, $p < .001$, $d = 0.32$).

As in Experiment 1 we found a reversed cueing effect in the conditions where the achromatic color of cue and target were different. RTs were slower in the valid-nonmatch condition ($M = 419$, $SE = 2.04$) than in the invalid-nonmatch condition ($M = 403$, $SE = 1.15$), which represents a small but significant reversed cueing effect of –16 ms ($t(5161.8) = 7.02$, $p < .001$, $d = 0.15$).

Table 1 on page 15 summarizes RTs and cueing effects of both experiments.

Reaction Times – ANOVA

Experiment 1. We analyzed the mean RTs with a repeated-measurements ANOVA with the within-subject variables cue position (valid vs. invalid) and cue color (match vs nonmatch) and found a significant main effect of cue color, $F(1, 15) = 6.97$, $p = 0.019$, and cue position, $F(1, 15) = 43.00$, $p < 0.001$. The interaction between cue-target color match and cue position was also significant, $F(1, 15) = 122.63$, $p < 0.001$), with an small to medium effect size $\eta^2 = 0.03$ (Bakeman, 2005; Maher, Markey, & Ebert-May, 2013).

Cues with the same achromatic color than the target elicited shorter RTs when preceding the target at the same position than at a different position whereas cues with a different achromatic color than the target elicited larger RTs when preceding the target at the same

Table 1

Mean of correct reaction times and cueing effects of Experiment 1 (dark targets) and Experiment 2 (light targets) in the four experimental conditions

	Position cue-target[a]			
Color cue-target	valid	invalid	Cueing effect[b]	Effect size (d)[c]
Experiment 1				
match	393	423	30	0.25
nonmatch	417	408	–9	0.07
Experiment 2				
match	387	423	36	0.32
nonmatch	419	403	–16	0.15

Note. Reaction times are in milliseconds. All cueing effect are significantly different from zero, $p < .001$.

[a]valid = same position, invalid = different position.

[b]invalid reaction times minus valid reaction times.

[c]Cohen's d measure of effect size; 0.2 = small, 0.5 = medium, 0.8 = large effect size (Cohen, 1988).

position than at a different position (reversed cueing effect). Both differences in RTs were significant and thus yielded to the significant interaction between cue position and cue color.

Experiment 2. The mean RTs in Experiment 2 were also analyzed using a repeated-measurements ANOVA and yielded essentially the same results. The main effect of cue color was significant ($F(1, 15) = 9.89$, $p = .007$) as well as the main effect of cue position, $F(1, 15) = 47.09$, $p < .001$. Again we found a significant interaction ($F(1, 15) = 142.36$, $p < 0.001$) with a large effect size, $\eta^2 = 0.15$.

As in Experiment 1 this interaction is also due to the cueing effects, that is, shorter RTs when a matching cue preceded the target at the same position than at a different position and a reversed cueing effect: higher RTs when a nonmatching cue preceded the target at the same position than at a different position. Figure 2 on page 19 shows the mean RTs of Experiment 1 and Experiment 2.

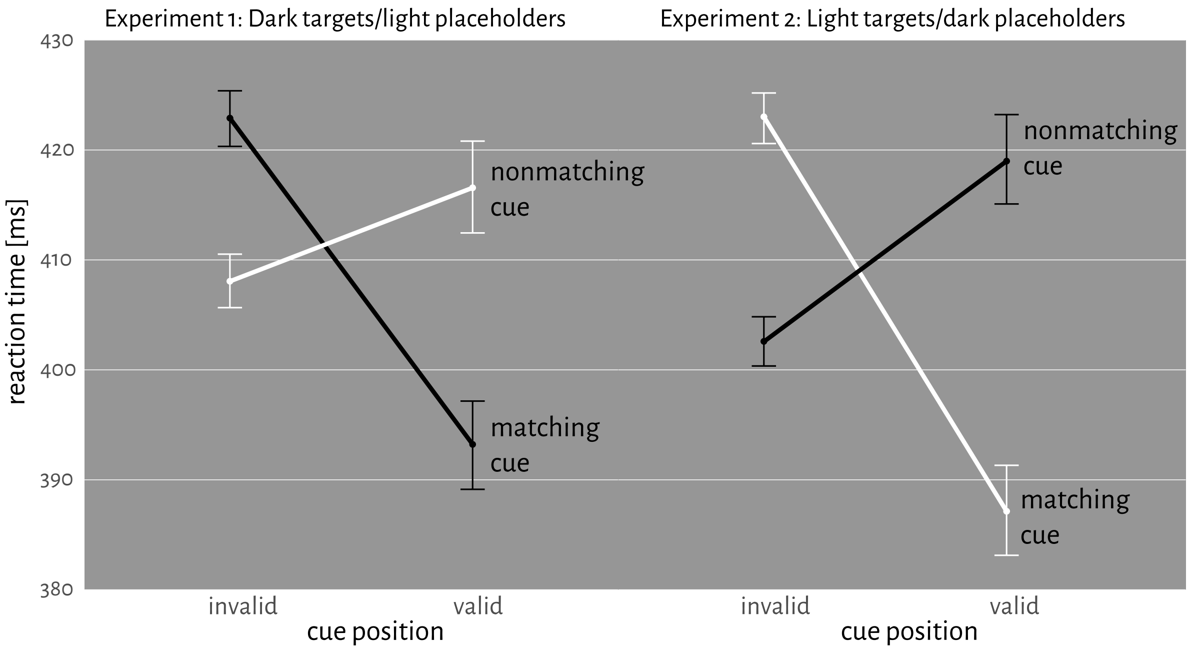

Figure 2. Mean reaction times with standard error bars in the four conditions showing the interaction between achromatic cue color (match vs. nonmatch) and cue position (valid vs. invalid) in Experiment 1 (dark targets, left side) and Experiment 2 (light targets, right side). Both experiments showed the same pattern: matching cues elicited a strong cueing effect (faster RTs in valid than invalid trials) and nonmatching cues a weaker reversed cueing effect (slower RTs in valid than invalid trials), see also Table 1 on page 18.

Error Rates

Experiment 1. We investigated wrong answers ($n = 1512$, time out errors were excluded) with loglinear analyses with the variables cue color (match vs. nonmatch) and cue position (valid vs. invalid). The most parsimonious model not deviating significantly from the data included only the effect of cue position, $\chi^2(2) = 3.25$, $p = .197$. This indicates that cue position had a significant effect on error rates, that is, more errors were made in invalid trials than in valid trials. Of course this is due to the fact that invalid trials occurred in 75 % of all trials whereas valid trials occurred only in 25 % of all trials. The two conditions of cue color (match vs. nonmatch) occured equally often and therefore the non-significant contribution of cue color to the final model indicates that there is no effect of cue color on error rates.

In a next step we used a chi-square test do investigate whether there is a deviance of error rates from the expected error rates under the assumption that the frequencies of errors did only depend on how often the conditions occurred. This is the null model were no effects are present. The results showed that the found error rates did not deviant significantly from the null model, $\chi^2(3) = 3.73$, $p = .293$, indicating that there is no effect on error rates.

Experiment 2. We used the same statistical procedure to analyze the error rates of Experiment 2, were $n = 1540$ wrong answers were recorded (time out errors were excluded). This time loglinear analysis produced a model with independent main effect as the most parsimonious model not significantly deviating from the data, $\chi^2(1) = 3.28$, $p = .07$, indicating that there were no interaction but both effect (cue position and cue color) contributed significantly to the model. The effect of cue position is found due to the different frequencies of valid and invalid trials, but the cue color conditions occurred equally often and therefore the effect of cue color represents a true effect on error rates

The further analysis with a chi-square test confirmed an effect of cue color on error rates. We found a significant deviance from null model, $\chi^2(3) = 8.63$, $p = .003$, caused by the higher occurrence of errors in the invalid-match condition and lower occurrence of errors in the invalid-nonmatch condition compared to the expected frequencies of the null model. The odds for errors in the invalid match conditions were 1.079 times higher than expected by chance, but only 0.909 in the invalid-nonmatch conditon, that is the odds for errors were 1.100 times lower than expected by chance in the invalid-nonmatch condition. These odds represent a very small effect size (Maher et al., 2013).

Figure 3 on page 21 shows the mosaic plot of the error rates for both experiment with the observed frequencies according to the null model in parentheses in the first and the relative frequencies in the second lines (expected values in parentheses). The numbers in the third lines are the standardized residuals of the observed values from the expected ones.

Discussion

With two experiments we investigated whether achromatic color can be used for top-down control of attention during search for onset targets and found evidence that the

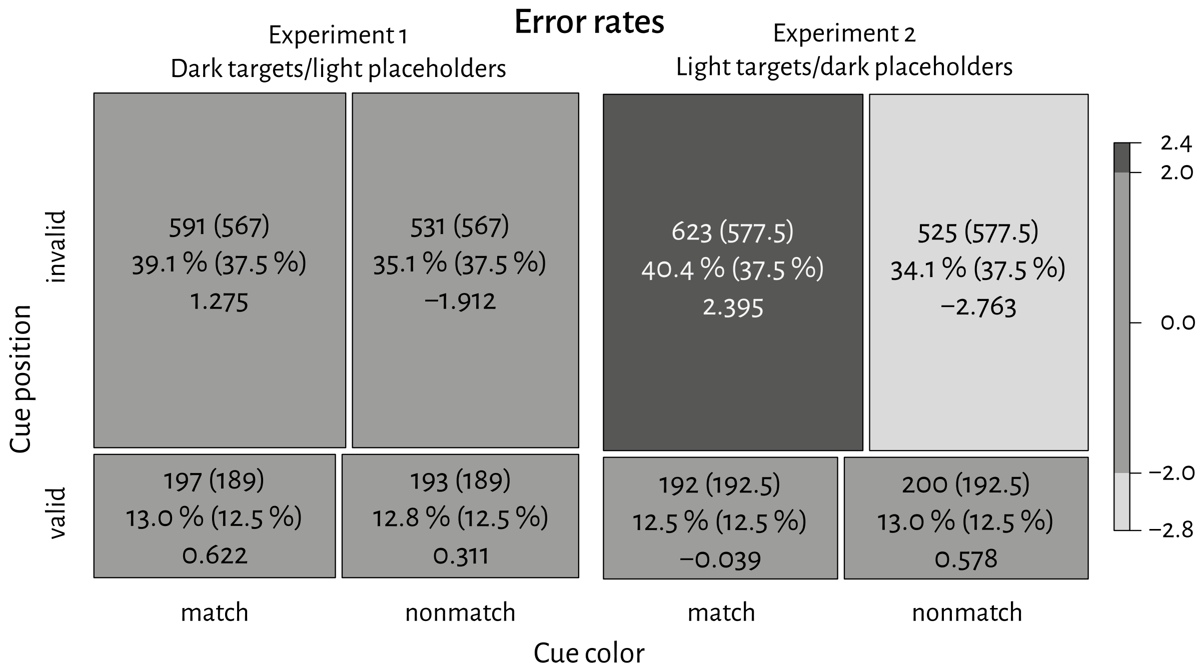

Figure 3. Error rates for both experiments with the observed frequencies and the expected frequencies according to the null model in parentheses in the first and the relative frequencies in the second lines (expected relative frequencies in parenthesis). The numbers in the third lines are the standardized residuals of the observed values from the expected ones.

achromatic color (dark or light) captured attention contingent on the achromatic color of the onset target.

If a cue with the same achromatic color than the target preceded the target at the same position, the RTs were significantly shorter than when the cues appeared at a different location than the target. An opposite effect was found for cues with a different achromatic color than the target: If such a nonmatching cue preceded the target at the same position, RTs were higher than when preceding the target at a different position. These finding are in line with the hypotheses that cues capture attention contingent on task-relevant features (Folk et al., 1992). Our results indicate that searching for a light (Experiment 1) or dark (Experiment 2) onset target leads to a top-down control setting for the achromatic color of the target. As a consequence, cues with the same achromatic color as the target match these top-down control setting and therefore capture attention. As light and dark cues had the same Weber contrast against the gray background, a stimulus-driven influence of luminance on capture of attention can be ruled out.

If participants search for onset targets they might use a top-down control setting specific to onset features or maybe a singleton detection mode (Bacon & Egeth, 1994), because an onset feature could be seen as an extreme form of a singleton. If participants had used a top-down setting only for onset features, the achromatic color singleton cues would not have elicited any cueing effects at all. On the other hand, if participants had used a top-down control setting based on singleton features, both achromatic color singletons (matching and nonmatching) would have elicited a cueing effect, because both cues were singleton cues, independent of their achromatic color. Our results are not compatible with this possibilities but indicate a capture of attention by cues with the same achromatic color as the target, which is in line with the contingent capture of attention hypothesis.

We found not only cueing effects elicited by achromatic color cues with the same color as the target but also reversed cueing effect elicited by cues with a different achromatic color as the target. That is, if a nonmatching cue preceded the target at the same position RTs were slower than when a nonmaching cue preceded the target at a different position. This reversed cueing effect elicited by nonmatching cues supports the conclusion that the achromatic color of the onset target was used for top-down control of attention, because the nonmatching cue were always singletons with a different achromatic color as the target among three stimuli with the same achromatic color as the target. Therefore, in case of an invalid nonmatching cue the three other positions were occupied by matching stimuli and one of these three positions were the position of the target. This results in faster RTs elicited by invalid nonmatching cues compared to valid nonmatching cues.

Assuming our reasoning is correct it remains unclear why the reversed cueing effect of nonmatching cues is no as strong as the cueing effect of matching cues. A possible explanation is that in the case of matching cues the attention is focused at one position whereas in the case of nonmatching cues the attention is more broadly focused at three position. According to the zoom lens model of attention (Eriksen & St. James, 1986) the window of attention influences the magnitude of cueing effects with a more focused window of attention eliciting stronger cueing effects compared to a more broad window of attention.

An alternative explanation is that the subsequent processing of information gets suppressed at the position of the nonmatching cue, which would also result in higher RTs in the valid-nonmatching condition compared to the invalid-nonmatching condition (cf. Lamy, Leber, & Egeth, 2004). With the experimental design used in this study it is not possible to differentiate between these two explanations.

The analysis of error rates showed that more errors as expected by the frequency of the conditions were made when the cues had the same achromatic color as the target but appeared at a different position (match-invalid condition). This increased error rate in trials with matching and invalid cues were only significant in Experiment 2, but the same tendency was observed in Experiment 1. Although the effect sizes were very small this tendency is in line with the capture of attention by the cue with the same achromatic color as the target. A matching but invalid cue captured the attention at a position where the target did not appear resulting not only in higher RTs but also in an increased error rate.

We conducted two experiments which differed only in two aspects: In Experiment 1 the targets were dark and the placeholder light whereas in Experiment 2 it was exactly the opposite (light targets and dark placeholders). Except for this difference both experiment were the same and we did not expect a difference. But nevertheless we found that in Experiment 2 (light targets) cueing effects elicited by matching cues and reversed cueing effects elicited by nonmatching cues were stronger compared to Experiment 1 (dark targets). Additionally the increased error rate in trials with matching and invalid cues reached significance only in Experiment 2, although we found a slightly increased error rate in trials with matching and invalid cues in Experiment 1 as well. This pattern of differences might indicate that light cues capture attention stronger or more effectively than dark cues, but the reason for that remains elusive and might inspire further research.

Terminology of Attention

As mentioned in the beginning, the terminology of attention became more complex as we learned more about the mechanisms of attention. Especially contingent capture of attention shows that automatic orientation of attention can occur dependent on top-down influences. Therefore top-down influences on orientation of attention are not necessarily controlled and voluntarily. Before further evaluating our results in the light of other research we try to clarify how terms regarding attention are used in this thesis.

The classification of factors in top-down and bottom-up has a long tradition and has proved useful. When it comes to attentional control mechanisms we classify stimulus-driven influences as bottom-up and internal influences as top-down. Internal influences subsume all processes inside an organism, for instance goals or intentions. Top-down influences are sometimes termed as goal-driven influence (Corbetta & Shulman, 2002), but in our opinion other internal factor like reward expectations or past experiences are top-down factors as well. Top-down influence on attentional control can be seen when an exact same display of stimuli elicits different behaviors depending on internal factors, for instance, goals or past experiences. On the other hand, if a stimulus elicits the same behaviors independent on internal factors, this stimulus-driven influence would be classified as bottom-up influence.

Awh, Belopolsky, and Theeuwes (2012) argued for a third factor additionally to top-down and bottom-up factors: selection history. They considered some forms of influence of past behavior (for example attending to a target in a preceding trial) on current behavior (inter-trial priming, Maljkovic & Nakayama, 1994) as a different form of influence than goal-directed influence. The need for a new category arose due to the assumption that goal-directed influence are equivalent with top-down influences. As mentioned above we consider all internal factors (including past experiences) as top-down influences and therefore it might not be necessary to assume a third factor to explain control mechanisms of attention.

Another useful classification was made by James (1890) when he contrasted active and voluntary attention with passive and reflexive attention. We refer to active and voluntary attention as controlled attention and term passive and reflexive attention as automatic attention (cf. Shiffrin & Schneider, 1977). It is important to point out that controlled attention is only possible based on top-down influences whereas automatic attention can be based on top-down (Folk et al., 1992) or bottom-up influences (Jonides, 1981; see also Ristic & Kingstone, 2012). Another often seen dichotomy is endogenous and exogenous attention (Posner, 1980; Carrasco, 2011). We consider endogenous attention as synonym for controlled attention and exogenous attention as synonym for automatic attention.

According to this terminology our results represent a form of automatic orientation of attention based on top-down factors. The top-down influence is obvious, because the capture of attention was contingent on the achromatic color of the target but our experimental design did not allow to explicitly test whether the attention was captured automatically. However, the cues did not inform the participants about the identity of the target and therefore were not useful for the task. Additionally, only in 25 % of the trials the cues were valid, thus there was little incentive to voluntary use the cue as a predictor of the target position, as this would lead in 75 % of all trials to an incorrect predicted target position. Participants were informed prior to the experimental session that the cue might predict the position of the target but that it is not necessarily so. Taken together it seems arguable that the participants did not attend voluntary to the cues and the capture of attention occurred automatically.

Top-down Influence on Attention

We showed in this study that achromatic color was used for top-down control of attention during search for onset targets. As we used only color singleton cues it was not possible to test for additional capture of attention by onset cues, but other studies showed that color and onset features were used simultaneously for top-down control of attention. During search for color onset targets attention is captured by onset cues independent of color, but if the onset cue has a similar color as the onset target, the cueing effect is even stronger (Ansorge & Heumann, 2003; Ansorge & Heumann, 2004).

Searching for a singleton target elicits top-down control of attention based on singleton features (or uniqueness). As a consequence, every singleton cue captures attention because the singleton feature meets the top-down control setting (Theeuwes, 1992). This singleton detection mode seems to be default and might be used whenever the search for a singleton or unique feature allows to find the target (Theeuwes, 2004). Singleton detection mode might be the default and preferred over feature search mode because it allows effective, parallel search (Treisman & Gelade, 1980). Bacon and Egeth (1994) forced participants to use a feature search mode by making it impossible to identify the target via search for singleton features. As a result an irrelevant singleton cue did not capture attention any more because the top-down control setting was not sensible for singleton features.

Leber and Egeth (2006) used singleton detection mode and feature search mode to demonstrate another top-down influence on attention: past experiences. Their participants completed a training phase where one group had to use a feature search mode to find the target whereas the other group could use a singleton search to find the target. After both groups had adopted a different search mode, the test phase started. In the test phase the participants of both group had to find a circle target among square targets. Thus it was possible to identify the target using a search for singletons (singleton detection mode). The group which adopted a singleton detection mode were distracted by irrelevant color singletons during the test phase, indication that their top-down control setting for singletons—acquired during the training phase—lead to automatic capture of attention by the color singletons even in the test phase. On the contrary, the participants of the group which adopted a feature search mode during the training phase were not distracted by irrelevant singleton color cues in the test phase, indicating that they used the feature of the target as top-down control setting for attention and not a singleton feature. The difference between the two groups occurred despite the test phase and the targets were exactly the same for both groups. The past experience modulated the mechanisms for orientation of attention. As past experiences are internal factors these modulations are considered a top-down influence, although the influence is not goal-directed, because the goal in the test phase was the same for both groups (see also Zehetleitner, Goschy, & Müller, 2012).

Interaction of Top-down and Bottom-up Influences

It is difficult to show pure bottom-up influence on orienting of attention due to the versatile possibilities of top-down influences (but see Franconeri, Simons, & Junge, 2004).

Nevertheless bottom-up factors interact with top-down factors in order to provide effective mechanism for orientation of attention. For example, stimuli might capture attention contingent on top-down control setting, but how efficiently a stimuli captures attention might also depend on the salience of the stimuli. Salience refers to the conspicuousness of a stimuli compared to its surroundings and depends among others on color, intensity and orientation (Itti & Koch, 2001).

Another bottom-up influence on top-down settings of attention is priming. For example if participants attended to a red target in a preceding trial, a red target in the current trial captured attention more efficiently (Maljkovic & Nakayama, 1994). A similar priming effect was shown when the target position were repeated in subsequent trials (Maljkovic & Nakayama, 1996). Inter-trial priming might contribute to reported contingent-capture effects, for instance, when the target color remains the same in each trial. But there are studies which suggest that this influence is relatively small (Lamy & Kristjansson, 2013).

The top-down influence on attention extends even to stimuli which are not consciously perceived (subliminal cues). McCormick (1997) investigated how awareness of a cue effects orienting of attention and showed that controlled orienting of attention was only possible if cues were perceived consciously (supraliminal cus), but nevertheless a subliminal cues did capture attention as well, probably in an automatic manner (McCormick, 1997).

Ansorge, Kiss, and Eimer (2009) investigated whether subliminal cues can capture attention depending on top-down control settings and found that subliminal cues with the same color as the target captured attention (for a similar result see Ansorge, Horstmann, & Worschech, 2010). Although it seems that top-down control of attention based on color is sensible for subliminal cues as well, this is not necessarily the case if the top-down control setting is based on achromatic color. Fuchs, Theeuwes, and Ansorge (2013) showed that when participants searched for dark onset targets the achromatic color of a subliminal onset cue did not contribute to the capture of attention. But this was not the case for supraliminal cues: If the cues were clearly visible the capture of attention depended on the task-relevance of the achromatic cue color. Furthermore, the supraliminal task-irrelevant achromatic color cue elicited a reversed cuing effect, which might indicate active suppression of supraliminal task-irrelevant cues (Fuchs et al., 2013).

It seems that some subliminal presented cues might capture attention independent of top-down factors, for instance, abrupt onset cues (Schoeberl, Fuchs, Theeuwes, & Ansorge, 2015) or faces (Finkbeiner & Palermo, 2009). But the top-down influence on attention does not depend on conscious processing of stimuli, although awareness might be necessary to form new top-down control settings (Ansorge, Kunde, & Kiefer, 2014).

Due to the interaction of top-down and bottom-up influences most theories of attention integrate both factors (Treisman & Gelade, 1980; Duncan & Humphreys, 1989; see also Petersen & Posner, 2012; Awh et al., 2012). In the Guided Search model (Wolfe, 1994; Wolfe, 2007) bottom-up factors (based on stimuli salience) were weighted by top-down control settings resulting in an activation map that guides attention. A similar approach was described by Awh et al. (2012). According to Awh et al. (2012) current goals, selection history and the salience of stimuli were integrated to form a priority map.

At a neuronal level this integration seems to happen via interaction of a dorsal frontoparietal network (associated with top-down factors) and a right ventral frontoparietal network, associated with bottom-up factors (Corbetta & Shulman, 2002). The dorsal frontoparietal network is influenced by the current visual input (at least color and shape), as well as by past experiences (Bichot & Schall, 1999). This might represent the bottom-up influence on top-down control mechanisms of attention. On the other hand, the right ventral frontoparietal network is more active if a stimulus is relevant for a goal (Gottlieb, Kusunoki, & Goldberg, 1998), which might represent a top-down influence on processing of current stimuli. An important function of the right ventral frontoparietal network is the orientation of attention to currently not processed but relevant stimuli by interrupting the dorsal frontoparietal network (Corbetta & Shulman, 2002; but see also Corbetta, Patel, & Shulman, 2008).

Posner and Petersen (1990), Petersen and Posner (2012) provided a neuronal framework for the attentional system in humans, consisting of an alerting system, an orienting system and a system for executive control. The alerting system controls general arousal and vigilance and is associated with the neuromodulator norepinephrine. High alertness improves reaction time and the speed of attentional orienting. The orienting system corresponds to the dorsal and right ventral frontoparietal network described by Corbetta and Shulman (2002) and is associated with the orientation of attention. The system for executive control is associated with top-down control of attention (Petersen & Posner, 2012).

The neuronal frameworks of attention seems to reflect the interaction between top-down and bottom-up factors on attentional control, which was found in behavioral experiments as well.

Conclusion

Our study adds another piece to the growing knowledge of top-down control of attention by showing that achromatic color can be used as a feature for top-down control of attention during search for onset targets. Future research should be aware of the possible confounding influence of achromatic color on contingent capture of attention.

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Appendix A

Curriculum vitae

Personal Information

Name	Markus Grüner
Born	15.10.1988 in Horn, Lower Austria, Austria
Citizenship	Austria
Residence	3814 Aigen bei Raabs, Lower Austria, Austria

Education

2013–2016	Master course Psychology, University of Vienna, Austria Focus: Psychological basic research
2010–2013	Bachelor course Psychology, University of Vienna, Austria
2009–2010	Bachelor course Business, Economics and Social Sciences Vienna University of Economics and Business
2003–2008	Business School, Waidhofen an der Thaya, Lower Austria, Austria Focus: International Business

Experience

06/2015–12/2015	Internship: University of Vienna Cognitive Psychology Unit
06/2010–today	Sidejob: Publishing House Berger, Horn, Lower Austria, Austria Marketing, PR, Funding, Account Management
09/2008–02/2009	Basic military service, Allentsteig, Lower Austria, Austria

Skills

Languages	German: Native Language English: Fluent French, Czech: Basics
Software	Microsoft Office Adobe Illustrator, Photoshop, InDesign, Dreamweaver LaTeX, Matlab
Programming	R, HTML, CSS

Appendix B

Abstract

Despite extensive research it is not yet entirely understood how the orientation of attention is influenced by top-down and bottom-up mechanisms. Here we investigated whether achromatic color (light and dark) can be used for top-down control of attention during search for onset targets. In two experiments participants (*N* = 32) searched for light (Experiment 1) or dark (Experiment 2) abrupt onset targets, preceded by supraliminal presented light or dark achromatic color singleton cues. According to the contingent capture of attention hypothesis only cues with task-relevant features capture attention, while cues with task-irrelevant features do not. We found that only cues with the same achromatic color as the target captured attention, whereas cues with the contrary achromatic color than the target did not. This confirms the contingent capture of attention hypothesis and indicates that achromatic color can be used as a feature for top-down control of attention during search for abrupt onset targets. We discuss the results relating to the scope and limits of top-down influences on control mechanisms of attention and the interaction with bottom-up influences.

Keywords: cueing, contingent capture of attention, achromatic color, onset target, singleton cue

Appendix C

Zusammenfassung

Trotz intensiver Forschung ist noch nicht völlig klar, wie die Verlagerung von Aufmerksamkeit von top-down und bottom-up Faktoren beeinflusst wird. In dieser Arbeit untersuchen wir, ob achromatische Farbe (hell und dunkel) zur top-down Kontrolle von Aufmerksamkeit verwendet werden kann. In zwei Experimenten suchten Versuchspersonen ($N = 32$) nach hellen (Experiment 1) oder dunklen (Experiment 2) plötzlich auftauchenden Zielreizen. Gemäß der Hypothese der zielreizabhängigen Verlagerung von Aufmerksamkeit wird die Aufmerksamkeit nur von Hinweisreizen angezogen, die aufgabenrelevante Merkmale besitzen, während Hinweisreize mit aufgabenirrelevanten Merkmalen die Aufmerksamkeit nicht anziehen. Es zeigte sich, dass nur Hinweisreize mit der gleichen achromatischen Farbe wie der Zielreiz die Aufmerksamkeit anzogen, nicht jedoch Hinweisreize mit der konträren achromatischen Farbe. Das bestätigt die Hypothese der zielreizabhängigen Verlagerung von Aufmerksamkeit und lässt darauf schließen, dass achromatische Farbe als Merkmal für top-down Kontrolle von Aufmerksamkeit verwendet werden kann, wenn nach plötzlich auftauchenden Zielreizen gesucht wird. Wir diskutieren die Ergebnisse in Bezug auf den Geltungsbereich und die Grenzen von top-down Einflüssen auf Kontrollmechanismen von Aufmerksamkeit und die Interaktion mit bottom-up Einflüssen.

Schlüsselwörter: Hinweisreize, zielreizabhängige Verlagerung von Aufmerksamkeit, achromatische Farbe, plötzlich auftauchender Zielreiz, Singleton Hinweisreiz