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Oculomotor capture by supraliminal and subliminal onset singletons: The role of contrast polarity

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ABSTRACT

According to a top-down explanation of subliminal oculomotor capture, only subliminal distractors with a contrast polarity matching that of the searched-for targets should capture attention. For instance, when looking for white targets only subliminal white but not black distractors should capture attention. In contrast, according to a bottom-up explanation of such capture effects, subliminal distractors with a contrast polarity different to that of the searched-for targets should also capture attention. For instance, even when looking for white targets, subliminal black distractors should capture attention. Here, we used subliminal singleton-onset distractors in the same vertical hemifield as the target versus singleton-onset distractors in the opposite vertical field to the target, and tested whether oculomotor capture by these distractors depended on a match between the searched-for target contrasts and the distractor contrasts, by measuring saccade latency, saccade trajectory deviation, and saccade endpoint deviation. We found evidence for oculomotor capture: subliminal distractors in the opposite field delayed saccade execution towards the target. This delay was found in comparison to subliminal distractors in the same hemifield as the target. In line with a bottom-up explanation, this delay was independent of the similarity between the distractor contrast polarity and the searched-for target contrast polarity. Together with the subliminality of the distractors, the experiment confirmed bottom-up oculomotor capture by subliminal singleton-onsets.

1. Introduction

Past research has demonstrated that unconscious or subliminal visual stimuli or features can capture attention (Ansorge, Kiss, & Eimer, 2009; McCormick, 1997; Mulckhuyse, Talsma, & Theeuwes, 2007; Scharlau, 2002; Van der Stigchel, Mulckhuyse, & Theeuwes, 2009). For example, Van der Stigchel, Mulckhuyse, and Theeuwes (2009) asked their participants to saccade to a visual target presented on the vertical meridian of a computer display (see Fig. 1). Prior to the target, these authors presented one singleton onset disk as a distractor. This distractor was offset to the left or to the right and it was shown either above or below fixation – that is, it was either in the same vertical half as the target or in the opposite vertical half. In subliminal conditions, participants remained unaware of the singleton-onset distractor because the distractor was shown for a very brief time (one refresh of the monitor) and just before three additional placeholders and the target at other locations. Due to the tiny interval between distractor and placeholders, participants did not consciously register the singleton onset of the distractor. Yet this onset distractor captured attention; the saccade trajectories deviated towards the distractor and away from the target. If the distractor was on the left, the saccade initially curved to the left, and if the distractor was on the right, the saccade curved to the right. Together with the participants' chance performance during the localization of the singleton-onset distractor this study demonstrated that subliminal distractors can capture attention.

However, it is unclear whether subliminal capture is bottom-up or top-down. On the one hand, some authors have claimed that subliminal stimuli capture attention in a bottom-up fashion (McCormick, 1997; Mulckhuyse, Talsma, & Theeuwes, 2007; Mulckhuyse & Theeuwes, 2010). According to this view, a subliminal stimulus would capture attention without any top-down attentional set directed to this stimulus or its features. For example, Van der Stigchel, Mulckhuyse, and Theeuwes (2009, p. 2105) argued that their distractors were completely task-irrelevant: "Note that the subliminal distractor was completely irrelevant and was not part of the attentional set of the participant: it did not resemble the target, it did not provide information about the appropriate response, it appeared at a location at which the saccadic target never appeared and participants did not have to report its presence in the session in which eye movements were recorded." Therefore, the participants' top-down controlled attentional set for particular

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relevant features did not seem to be responsible for oculomotor capture by the subliminal distractors. By implication, Van der Stigchel et al. suggested that bottom-up capture was responsible for their oculomotor capture.

On the other hand, researchers argued for a decisive role of top-down attentional control sets for capture by subliminal stimuli (Ansorge, Kiss, & Eimer, 2009; Ansorge, Horstmann, & Worschech, 2010; Held, Ansorge, & Müller, 2010). According to the top-down contingent capture view, only stimuli that match the searched-for target features would capture attention (Folk, Remington, & Johnston, 1992). In the past, this top-down contingent-capture principle has been confirmed with subliminal stimuli. For example, presenting their participants with one subliminal distractor per trial, Ansorge, Horstmann, and Worschech (2010) observed attentional capture for distractors with a color similar to the searched-for target color but failed to find evidence for capture by subliminal distractors with a color different from that of the target. For instance, if participants searched for a red target, a subliminal red distractor captured attention but if participants searched for a green target, a subliminal red distractor did not capture attention.

Of course, top-down control might also be exerted by the successful suppression of attentional capture by irrelevant information (Theeuwes, Atchley, & Kramer, 2000). Like contingent capture, top-down suppression should be easier with stimuli of lower resemblance to the searched-for target features than with stimuli that better match the searched-for target features. Like contingent capture, top-down suppression should lead to less capture by subliminal stimuli that differ (e.g., in their color) from the searched-for target features than by stimuli that are more similar to the searched-for target features. However, in contrast to the contingent-capture view, according to the suppression view it is sometimes claimed that at least an initial phase of bottom-up attentional capture could be spared from successful suppression (Theeuwes, Atchley, & Kramer, 2000).

Against the background of conflicting views and findings, we tested the role of top-down attentional sets for oculomotor capture. Potentially at odds with an assumed complete irrelevance of the subliminal distractors in the study of Van der Stigchel, Mulckhuyse, and Theeuwes (2009), these authors used distractors of the same contrast polarity (or of the same achromatic color) – that is, light gray distractors against a gray background – as was used for the searched-for relevant light gray targets. Therefore, it is possible that oculomotor capture in Van der Stigchel et al. reflected top-down contingent capture. For example, the participants could have intentionally searched for a light gray onset stimulus, because this stimulus indicated that the target display had started (cf. Gibson & Kelsey, 1998). If the participants indeed searched for light gray stimuli, a subliminal light gray onset distractor sharing its contrast or achromatic color with the searched-for signal could have captured attention in a top-down contingent way.

To test this possibility, in the current study we let our participants saccade to one known fixed target contrast throughout the experiment, and systematically varied the fit or match between the distractor's polarity contrast and that of the task-relevant target. In top-down matching conditions, distractors were of the same contrast polarity as the targets. For example, if participants searched for white targets, matching distractors were also white. In non-matching conditions, distractors had a contrast polarity that was different to that of the targets. For example, if participants searched for white targets, a black distractor was used as a non-matching distractor. We expected that if oculomotor capture was bottom-up, black and white subliminal singleton-onset distractors should capture attention, regardless of the currently pertaining top-down attentional control set of the participants (Fuchs, Theeuwes, & Ansorge, 2013). In contrast, under the perspective of the top-down capture theory, a subliminal distractor should only capture attention if the distractor's contrast polarity matched that of the searched-for relevant targets.

In addition to the subliminal distractor condition, in separate blocks, we looked at oculomotor capture by supraliminal distractors. In supraliminal conditions, no additional placeholders were shown together with the target so that the singleton onset of the distractor could be clearly seen. Supraliminal distractors were expected to capture attention (McSorley, Cruickshank, & Inman, 2009; McSorley, Haggard, & Walker, 2004, 2006).

Also, we did not only look at saccade trajectories. We also looked at saccadic endpoints and saccadic onsets. With respect to the saccadic endpoints, a shift towards the distractor had previously been found when a subliminal distractor had been presented in the same vertical hemifield as the target (Van der Stigchel, Mulckhuyse, & Theeuwes, 2009). With respect to saccadic onsets, a delayed onset of the saccades had previously been reported when a supraliminal distractor was presented in the opposite vertical hemifield as compared to the same vertical hemifield (Van der Stigchel, Mulckhuyse, & Theeuwes, 2009).

Finally, in subliminal and supraliminal conditions, we ran additional blocks after the saccade tasks to check whether the subliminal distractors were truly subliminal and whether the supraliminal distractors could be seen. These tests were always administered at the end of the experiment so as (1) not to additionally increase the task relevance of all distractors and (2) not to give away information about the presence and nature of the subliminal distractors in the first place.

2. Material and methods

2.1. Participants

Twenty-six students at the University of Vienna (20 female; mean age 22.9 years, range 18–38) took part. They participated on a voluntary basis or in exchange for course credit. All had normal or corrected to normal vision. The dominant eye was the left eye for 12 participants and the right eye for 14 participants. Informed consent was obtained from each participant.

2.2. Apparatus

Stimuli were presented on a 19″ CRT monitor (Sony Multiscan G400) with a resolution of 1024 × 768 pixels and a refresh rate of 120 Hz. Stimulus presentation was programmed using Experiment Builder software (SR Research Ltd., Canada). Eye movements were registered using an EyeLink 1000 Desktop Mount (SR Research Ltd., Canada), with a sampling rate of 1000 Hz, a gaze position accuracy of <0.5°, and a spatial resolution of <0.01°. Data from the dominant eye was monitored and analyzed. The eye tracker was positioned under the monitor. The eye tracker was individually calibrated for each participant before the experiment started. A keyboard was placed in front of the participants. A table lamp served as an indirect light source behind the monitor. The room was quiet. A chin rest and forehead bracket ensured a viewing distance of 64 cm.

2.3. Stimuli and procedure

The procedure was adapted from Van der Stigchel, Mulckhuyse, and Theeuwes (2009), see Fig. 1. The experiment consisted of two parts. The first part was a *saccade task*; the second part was a *distractor-report task*. During the first part the saccades were registered. Participants were instructed to fixate on a central fixation cross and to make an eye movement to the diamond-shaped target as accurately and quickly as possible. During the second part, participants indicated in which of four quadrants around screen center the distractor had been presented (as Fig. 1 shows examples of a trial used in our study).

In both parts, all stimuli were presented on a gray background (72.5 cd/m^2). Each trial started with the fixation cross. The fixation cross was a plus sign in the middle of the screen. It disappeared after 1400 ms (plus a random jitter between 0 and 400 ms). Next, the singleton-onset distractor appeared 16 ms before the disappearance of the fixation cross. This distractor was a filled disk of 1.4° diameter. It appeared at one of four corners of an imaginary square around the fixation cross. After 16 ms, the fixation cross was turned off and, depending on the block, one of two displays was shown. In the *subliminal* block, three additional disks of the same size and contrast as the first disk appeared as placeholders on the remaining corners of the imaginary square. In the *supraliminal* block, the target appeared without the three placeholders after 16 ms. The distance of the fixation cross to the center of the disks was 7.6°. Simultaneously with the three disks (in subliminal conditions) or one frame after the distractor (in supraliminal conditions) the target appeared above or below the imaginary square. Target positions were randomized across trials. The target was a diamond of 1.8° diameter. The distance between the fixation cross and the target was 9.1°.

The distractor appeared above or below the fixation cross, either in the same vertical field as the target (*same field condition*), or in the opposite vertical field (*opposite field condition*). In the *neutral condition* there was no distractor presented before the onset of the target. The disks and the target were black (or dark; 23 cd/m^2) and white (or light; 122 cd/m^2). Whether the target was black or white was balanced across participants. Half of the participants had to search for black targets, the other half for white targets. The distractor and the placeholders were of the same contrast polarity as the target (*same polarity*) or of the different polarity (*different polarity*). The polarity of the distractors and their locations varied randomly across trials. The inter-trial interval between the target and the start of the next trial was 1 s.

Participants started with the saccade task. The saccade task began with 25 practice trials. During the practice trials the eye movements were not registered. After practice, the saccade task proper started. It consisted of two consecutive blocks, each with 192 trials (384 trials in total). Supraliminal versus subliminal distractors were blocked. The order of the blocks was balanced across participants. Within each block, neutral, same-field, and opposite-field trials were equi-probable, and orthogonally crossed with the polarity of the distractors. When a saccade was elicited faster than 80 ms or slower than 600 ms after the target, a warning appeared on the screen about the saccade being too fast or too slow. Warning trials were repeated at the end of the saccade task. Also, there was a break after every 64 trials.

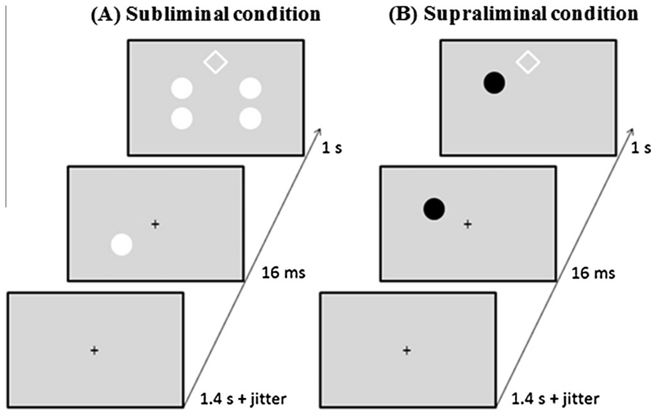

Fig. 1. Depicted are examples of a trial with a subliminal same contrast polarity distractor in the field opposite to the target (A) and with a supraliminal different contrast polarity distractor in the same field as the target (B). Conditions on the left correspond to the subliminal conditions of Van der Stigchel, Mulckhuyse, and Theeuwes (2009).The arrows depict the flow of time. Stimuli are not drawn to scale.

After the two blocks of the saccade task, the distractor-report task was administered. The design of each trial was the same as in the saccade task. After each trial the fixation cross reappeared with the numbers 1, 3, 7, and 9 at the corners of the imaginary square. The participants were instructed to indicate the location of the distractor by pressing keys *#1, #3, #7,* or *#9* on the number keypad of a standard keyboard. The spatial layout of the keys corresponded to the layout of the possible locations of the distractors. Participants were told to ignore the target for their distractor judgments. They were encouraged to answer quickly and informed that guessing is often better than chance performance. The order of the blocked subliminal and supraliminal conditions was the same as in the saccade task. Each distractor-report block consisted of 64 trials (128 trials in total). Within the two blocks, the conditions same field and opposite field and same polarity and different polarity were again orthogonally crossed and randomized across trials. There was no neutral condition in the distractor-report blocks. Before and after each block of the distractor-report task, the following condition (subliminal or supraliminal) was explained. During the distractor-report task the saccades were not registered but the participants kept their heads on the chin rest and leaned against the forehead bracket.

2.4. Data analysis

Data Viewer (SR Research Ltd., Canada) was used to determine saccades. A saccade was defined as correct if the saccadic starting point was within 1° around the center of the fixation cross and if the saccade endpoint lay within an area of 2° around the center of the target. Incorrect saccades were excluded. Saccade latencies were calculated as the times when the eye velocity exceeded 30°/s and the acceleration was above 8000°/s^2. Saccades with latencies of less than 80 ms and more than 600 ms were not analyzed.

Saccade endpoint deviation was calculated as the horizontal distance between saccade endpoint and the center of the target in degrees of visual angle. Saccade trajectories were calculated as in Van der Stigchel, Mulckhuyse, and Theeuwes (2009; for an overview of saccade trajectory calculation see Van der Stigchel, Meeter, & Theeuwes, 2006). The angles between the starting point of the saccade and the different saccadic points (one per each millisecond) were calculated and averaged for the whole saccade. This averaged angle of the actual saccade was subtracted from the angle of a straight line between starting and endpoint of the saccade. Horizontal deviations of the saccade trajectories and of the saccade endpoints were labeled relative to the distractor. Deviations in the direction of the distractor were labeled with a plus sign. Deviations in the opposite direction were labeled with a minus sign.

3. Results

3.1. Distractor-report task

One-tailed-binomial tests for each participant showed that two of the 26 participants had a result significantly above chance level (25%) in the subliminal condition.[1] In the supraliminal condition,

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[1] Van der Stigchel, Mulckhuyse, and Theeuwes (2009) excluded their participants ($N = 5$) with a better-than-chance localization of subliminal distractors in the distractor-report task. When we excluded our two participants with better than chance performance in the discrimination of the subliminal distractors, the pattern of results did not change.

every participant scored significantly above chance level. One-sample t-tests (against 25%) revealed an above-chance accuracy in the subliminal (27.94%), $t(25) = 3.0$, $p = .003$, and in the supraliminal condition (93.72%), $t(25) = 27.27$, $p < .001$. In addition, t-tests revealed that there was no significant block order effect (subliminal block first versus supraliminal block first) for the subliminal as well as the supraliminal condition (all $ps > .13$).

3.2. Saccade task

A three-way repeated measures ANOVA with the within-participant variables distractor *awareness* (subliminal distractor, supraliminal distractor), *field* (same field, opposite field), and *contrast polarity* (same polarity, different polarity) was calculated for saccade latencies, saccade trajectory deviations, and saccade endpoint deviations. In addition, we analyzed the relationship between saccade latency and trajectory as well as endpoint deviation. The neutral condition could not be included as an orthogonal factor because there was no distractor. It was included in the design to ensure that conditions were the same as in the study of Van der Stigchel, Mulckhuyse, and Theeuwes (2009). Pairwise comparisons are Bonferroni-adjusted.

3.2.1. Saccade latency

The three-way repeated measures ANOVA on saccade latencies showed a significant main effect for contrast polarity, $F(1,25) = 42.21$, $p < .001$; $\eta_p^2 = .63$, with a lower latency in the different polarity condition (231 ms) than in the same polarity condition (240 ms). There was a significant main effect for field, $F(1,25) = 120.08$, $p < .001$, $\eta_p^2 = .83$, showing a distractor effect on latencies, with a lower latency in the same field condition (230 ms) than the opposite field condition (242 ms). Finally there was a significant main effect for awareness, $F(1,25) = 40.62$, $p < .001$, $\eta_p^2 = .62$, with a lower latency in the supraliminal condition (229 ms) than in the subliminal condition (243 ms).

The interaction between contrast polarity and field just failed to become significant, $F(1,25) = 4.21$, $p = .051$, $\eta_p^2 = .14$, reflecting a larger difference between same and opposite fields in the same polarity condition (same field: 234 ms, opposite field: 247 ms, $p < .001$) than in the different polarity condition (same field: 226 ms, opposite field: 236 ms, $p < .001$). The interaction between contrast polarity and awareness was significant, $F(1,25) = 23.51$, $p < .001$, $\eta_p^2 = .49$. The difference between same and different polarities was larger in the subliminal condition (same polarity: 250 ms, different polarity: 236 ms, $p < .001$), than in the supraliminal condition (same polarity: 231 ms, different polarity: 226 ms, $p = .002$). The interaction between field and awareness was significant, $F(1,25) = 66.96$, $p < .001$, $\eta_p^2 = .73$. The difference between same and opposite field was larger in the supraliminal condition (same field: 219 ms, opposite field: 238 ms, $p < .001$) than in the subliminal condition (same field: 241 ms, opposite field: 245 ms, $p < .001$) which shows a larger distractor effect for the supraliminal condition. The results are depicted in Fig. 2.

The three-way interaction was not significant ($p = .66$). In order to reduce a possible skew of the latency data, we performed an additional three-way repeated measures ANOVA based on log-transformed data. The pattern of results did not change. A mixed-design ANOVA with target polarity and block order (subliminal versus supraliminal block first) as between-subjects variables revealed a significant interaction between field and block order, $F(1,22) = 8.26$, $p = .009$, $\eta_p^2 = 0.27$. The difference between same and opposite field was larger in the subliminal first group (same field: 224 ms, opposite field: 239 ms, $p < .001$) than the supraliminal first group (same field: 235 ms, opposite field: 244 ms, $p < .001$). To compute the influence of the distractor, we compared the same and opposite field condition with the neutral condition. T-tests revealed that the saccade latency in the neutral condition (238 ms) was slower than the average saccade latency in the same field condition (230 ms), $t(25) = -8.29$, $p < .01$, and faster than the saccade latency in the opposite field condition (241 ms), $t(25) = 2.98$, $p < .01$.

3.2.2. Saccade trajectory deviation

The three-way repeated measures ANOVA on saccade trajectory deviations showed a significant main effect for field, $F(1,25) = 6.42$, $p = .018$, $\eta_p^2 = .20$. The deviation away from the distractor in the opposite field condition (−0.004 rad) differed significantly from the deviation towards the distractor in the same field condition (0.004 rad). The significant interaction between field and awareness, $F(1,25) = 5.67$, $p = .025$, $\eta_p^2 = .19$, showed that the significant difference between the same and opposite field condition only existed in the supraliminal condition (same field: 0.006 rad, opposite field: −0.009 rad, $p = .009$). The difference between the same and opposite field in the subliminal condition was not significant (same field: 0.002 rad, opposite field: 0.001 rad, $p = .804$). The main effects for contrast polarity and awareness, and the interactions between contrast polarity and field, and between contrast polarity and awareness, as well as the three-way interaction were all not significant (all $ps > .37$). One-sample t-tests revealed that there was no significant difference between the saccade trajectory deviation of each condition and zero (all $ps > .06$). A mixed-design ANOVA with target polarity and block order (subliminal versus supraliminal block first) as between-subjects variables revealed neither significant main effects of these two variables, nor any interactions between these variables and field, contrast polarity, or awareness (all $ps > .07$).

3.2.3. Saccade endpoint deviation

The three-way repeated measures ANOVA on saccade endpoint deviations showed a significant main effect for field, $F(1,25) = 9.11$, $p = .006$, $\eta_p^2 = .27$. The deviation away from the distractor in the opposite field condition (−0.03°) differed significantly from the

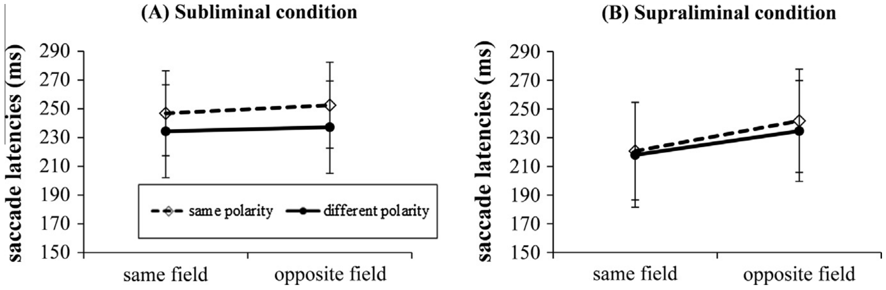

Fig. 2. Depicted are the mean saccade latencies and standard deviations of the conditions same and opposite field separately for same and different polarity distractors for the subliminal (A) and the supraliminal (B) condition.

deviation towards the distractor in the same field condition (0.10°). The significant interaction between field and awareness, $F(1,25) = 7.84$, $p = .01$, $\eta_p^2 = .24$, showed that the significant difference between same and opposite field only existed in the supraliminal condition (same field: 0.17°, opposite field: −0.82°, $p = .001$). The difference between the same and opposite field in the subliminal condition was not significant (same field: 0.03°, opposite field: 0.02°, $p = .873$). The significant interaction between field and contrast polarity, $F(1,25) = 7.62$, $p = .011$, $\eta_p^2 = .23$, showed that a significant difference between same and opposite field only existed in the same polarity condition (same field: 0.16°, opposite field: −0.09°, $p = .002$). The difference between same and opposite field in the different polarity condition was not significant (same field: 0.04°, opposite field: 0.04°, $p = .907$). The main effects for contrast polarity and awareness, the interaction for contrast polarity and awareness, and the three-way interaction were all not significant (all $ps > .15$). One-sample t-tests revealed a significant difference from zero in the conditions same polarity, opposite field, supraliminal, mean: -0.17°, $t(25) = -2.34$, $p = .028$, and same polarity, same field, supraliminal, mean: 0.26°, $t(25) = 3.05$, $p = .005$. None of the other conditions differed significantly from zero (all $ps > .23$). A mixed-design ANOVA with target polarity and block order (subliminal versus supraliminal block first) as between-subjects variables revealed neither significant main effects of these two variables, nor any interactions between these variables and field, contrast polarity, or awareness of these two factors (all $ps > .05$).

3.2.4. Relationship between saccade latency and deviations

To analyze the relationship between saccade latency and trajectory as well as endpoint deviation, we first grouped the latency distribution for each subject into bins of 20% (quintiled). The mean latencies of each bin were 193, 216, 233, 254, and 298 ms. The trajectory and endpoint deviations within each bin were averaged across subjects. A two-way repeated measures ANOVA with the within-participant variables *field* (same field, opposite field) and *bin* (five levels) on saccade trajectory deviation revealed a significant interaction between field and bin, $F(4,22) = 3.58$, $p = .022$, $\eta_p^2 = 0.39$. Pairwise comparisons showed that there was a significant difference between the third (0.007 rad) and the fifth bin (−0.02 rad) in the opposite field condition ($p = .006$). No other effects were significant. A two-way repeated measures ANOVA with field and bin as within-participant variables on saccade endpoint deviation showed the main effect of field, $F(1,25) = 8.17$, $p = .008$, $\eta_p^2 = 0.25$ (same field: 0.10°, opposite field: −0.01°). However, no other effects were significant.

4. Discussion

In the present study, we tested whether subliminal oculomotor capture is bottom-up or top-down. A subliminal distractor in the opposite field delayed the onset of a saccade towards the target. This delay was found in comparison to a subliminal distractor in the same field. In line with a bottom-up effect, this location-specific delay was found regardless of the match between the contrast polarity of the distractor and that of the searched-for targets.

Admittedly, the distractor effect on saccadic latencies was on average (across subliminal and supraliminal conditions) stronger for distractors of the same polarity as the targets. This might be an indication that the top-down control set also played a role for the amount of oculomotor capture. However, what counts under the perspective of the bottom-up capture view is the fact that there was significant oculomotor capture by non-matching subliminal distractors, too. Thus, a match between the searched-for target contrast and that of the distractor is a supporting, though not a necessary, prerequisite of capture by subliminal onsets. It is also important to note that oculomotor capture was spatial in nature: the delay of saccade onset latency was (mostly) caused by distractors in the opposite field relative to distractors in the same field. Thus, we can rule out an explanation of the oculomotor capture effect in terms of non-spatial filtering costs (cf. Folk & Remington, 1998). The subliminality of the cues could be doubted in light of the above-chance accuracy in the distractor-report task. However, all participants subjectively reported not to have seen the subliminal distractors, meaning that a subjective criterion of subliminality was definitely met (Merikle, Smilek, & Eastwood, 2001). To note, above-chance accuracy in the distractor report task may have also reflected subliminal rather than supraliminal effects of the distractors because motor priming of subliminal cues via direct parameter specification would have been possible (cf. Neumann, 1990). In other words, in our use of a maximally exhaustive visibility test, we might have inadvertently corrupted the exclusivity criterion (Reingold & Merikle, 1988).

Besides this bottom-up capture by subliminal onsets in the saccade latencies, a number of further, partly unexpected results were observed. Most critically, we were not able to replicate the effect of the subliminal distractors on saccade curvature that was found by Van der Stigchel, Mulckhuyse, and Theeuwes (2009). Also, compared to a straight line, saccade curvature effects of the distractors were not even found when supraliminal distractors were used. In general, this finding might not be too surprising because we averaged across fast and slow saccades. Therefore, we averaged across trajectory deviations toward the distractor in faster saccades and away from the distractor in slower saccades (cf. McSorley, Haggard, & Walker, 2006). This relationship could be shown comparing the third and the fifth bin of latency in the opposite field condition. Whereas there was a deviation towards the distractor with shorter latencies, the saccade deviated away with longer latencies. If both tendencies contributed to the average trajectories in the current study they might have cancelled one another out. In line with this possibility, in the current study saccade latencies in the subliminal condition (243 ms) were on average 26 ms higher compared to Van der Stigchel et al. (217 ms), and in the supraliminal condition of the present study (229 ms) they were 45 ms higher than in Van der Stigchel et al. (184 ms). Thus, the small curvature towards the distractors found by Van der Stigchel et al. could be due to a larger contribution of faster saccades to their total number of all saccades.

4.1. Further effects on saccade latency

Also of interest, in the latency analysis we found main effects and interactions that suggested (1) a stronger amount of oculomotor capture under supraliminal than under subliminal conditions, (2) and a stronger influence of distractor awareness in the same field than in the opposite field conditions. With respect to (1) – the stronger oculomotor capture effect of supraliminal than subliminal distractors – a partly similar pattern was observed in Van der Stigchel, Mulckhuyse, and Theeuwes (2009). In that study, saccade latency was selectively affected by supraliminal distractors but it was not affected by subliminal distractors.

What factor might have caused a weaker field effect of the subliminal distractor? In general, a weaker field effect in the subliminal condition could be due to the placeholders that were used in the subliminal condition only. Because the placeholders potentially attracted attention, too, they probably counter-acted the position-specific effect of the subliminal onset distractors. In line with this assumption of placeholder-elicited interference, in the subliminal conditions latencies were on average delayed relative to the supraliminal condition. Also, no capture by placeholders would have counteracted the field effect of the supraliminal distractors. This means that the capture of the supraliminal distractor was measured free of capture towards other positions.

With respect to (2), we found that the supraliminal distractor in the same field facilitated saccades toward the target. This was in comparison to the influence of a subliminal distractor in the same field. In contrast, the difference between supra- and subliminal distractors in the opposite field was much weaker. This interaction might indicate that participants could make use of the supraliminal distractors when programming the vertical direction of their next target-directed saccade. As a consequence of such use of buffered direction information from the distractor, less time for the programming of the next target-directed saccade would have been required with a supraliminal distractor in the same field as the target.

In general agreement with this possibility, studies have shown that saccade programming consists of two partly dissociable steps: the programming of the direction of a saccade, and the programming of the amplitude of a saccade (Becker & Jürgens, 1979). Moreover, past research has shown that if a new target location is specified early enough after a first potential saccade target stimulus has been presented, (1) a saccade can be immediately directed to the new target position, and (2) this correct saccade can benefit from the direction information contained in the first stimulus (Aslin & Shea, 1987; Hou & Fender, 1979). Therefore is it possible that attention capture by the supraliminal distractor presented in the same vertical field allowed a faster programing of the saccade to a target and provided a benefit of 19 ms compared to a supraliminal distractor in the opposite vertical field. This benefit is confirmed by the shorter latency in the same field condition compared to the neutral condition.

The fact that this advantage was not observed with subliminal distractors might mean that this benefit is partly counteracted by the placeholders in the subliminal conditions. In fact, if all the placeholders captured attention to some degree, it would be no wonder that on average less information about the trajectory of the target-directed saccade could be fetched from localization of the subliminal distractors. Alternatively, the fact that this same-field advantage was not found with subliminal distractors might also mean that the benefit provided by the same-field distractor is (partly) strategic. In line with this assumption, past research showed that participants can only use supraliminal onsets in a strategic way for the programming of their next attention shift, but that participants are not able to strategically use subliminal onsets for that purpose (Experiment 4 of Fuchs & Ansorge, 2012).

In addition to these interactions, in the analysis of the saccade latencies, we also found (3) an almost significant interaction of contrast polarity and field, and (4) a significant interaction of contrast polarity and awareness. The explanation for (3) – a stronger field effect with distractors of the same contrast polarity as the searched-for targets than with distractors of a different contrast – could be top-down contingent capture. A selective capture effect of the top-down matching same-color distractors is the standard finding in support of the contingent capture theory, both with supraliminal distractors (Folk & Remington, 1998; Folk, Remington, & Johnston, 1992) and with subliminal distractors (Ansorge, Kiss, & Eimer, 2009; Ansorge, Horstmann, & Worschech, 2010). The fact that this contingent capture effect only bordered on significance here neatly aligns with the observation of a significant capture effect in the non-matching conditions. Above, we have concluded that the oculomotor capture effect in the non-matching conditions speaks for bottom-up capture. This raises the question why contingent capture might have been weaker in the present study than in former experiments.

One reason why contingent capture was weaker in the present study as compared to prior studies is probably that we used subliminal distractors. Fuchs, Theeuwes, and Ansorge (2013) have recently shown that contingent capture can be much stronger with supraliminal than with subliminal onset distractors. A second reason why contingent capture was weaker in the present study as compared to prior studies is the use of a very short distractor-target interval of only 16 ms in the present experiment. Using similarly short intervals, past studies have sometimes found residual interference by non-matching distractors, too (Ansorge & Heumann, 2003). Such interference by an irrelevant distractor and with a short distractor-target interval might be due to initial bottom-up capture by the distractor. Such initial bottom-up capture would be overcome by reallocation of attention to a neutral point when the distractor-target interval is longer (Theeuwes, Atchley, & Kramer, 2000). Hence, a short distractor-target interval in the present experiment could have increased the sensitivity of the saccade latencies for residual bottom-up capture. Third, singleton onsets might be especially powerful bottom-up attractors of attention (Theeuwes, 2010). Whereas numerous studies have falsified the existence of initial bottom-up capture by salient color stimuli with the help of event-related potentials (ERPs) (e.g., Eimer & Kiss, 2008), for technical reasons alone no ERP study has convincingly demonstrated the same absence of initial bottom-up capture by singleton onsets. Thus, it is possible that singleton onsets capture attention at least partly in a bottom-up way. This would also explain why studies that used subliminal color singleton rather than onset singletons found top-down contingent capture (Ansorge, Kiss, & Eimer, 2009; Ansorge, Horstmann, & Worschech, 2010). In summary, three factors – the subliminality of the distractors, the short distractor-target intervals, and the use of singleton onsets as distractors – could have combined to potentially increase the sensitivity of the present procedures for bottom-up capture.

Now let us turn to (4) – the longer saccadic onset times with same-contrast polarity than different-contrast polarity distractors that was especially strong with subliminal distractors but less so with supraliminal distractors. Two explanations for this interaction are conceivable. First, the stronger interference by the same-contrast polarity distractors could have reflected top-down contingent capture, too. If the singleton-onset distractor's field effect was at least partly mediated via a match of the singleton to the top-down control sets as we have reviewed above, then capture by the placeholders in only the subliminal conditions could have been equally conditional on such a match between the placeholders and the attentional set. As a consequence, we would have observed the pattern of results that we found: more interference in the same contrast conditions, especially where a larger number of stimuli competes for attention – that is, in the subliminal conditions with its placeholders. This top-down explanation is in line with findings and theories of visual search. In visual search a high target-distractor similarity makes search more difficult because it would increase the competition between target and the distractors that would both match the search set to some degree, and this difficulty would be proportional to the number of distractors in the display (e.g., Duncan & Humphreys, 1989; Wolfe, 1994).

Alternatively, the interaction of contrast polarity and field could have little to do with top-down contingent capture of attention. It could have also reflected that the target did not pop out as strongly between the distractor(s) of the same contrast polarity as it popped out among the distractors of the opposite polarity (Nothdurft, 1993; Treisman & Gelade, 1980). According to this interpretation, distractors of a similar contrast polarity as the target that were present in the subliminal conditions would have compromised the target's stimulus-driven pop-out capture effect that would otherwise have facilitated the correct localization of the target (cf. Nothdurft, 1993; Theeuwes, 2010).

4.2. Saccade endpoints

With respect to saccade endpoints, we found selective oculomotor capture with supraliminal distractors but no capture with subliminal distractors. In the same analysis, a two-way interaction between contrast polarity and field indicated that the field difference was selectively present with the same-contrast polarity distractors. Only with same-contrast polarity distractors, saccade endpoints deviated toward the distractor in the same field, whereas they deviated away from the distractors in the opposite field. This finding is reminiscent of the results of McSorley, Haggard, and Walker (2006) who found that fast saccades curved toward the distractors, and slow saccades away from the distractors. Because, in the present study, saccades to targets in the presence of a distractor in the same field were faster than saccades to targets with a distractor in the opposite field, a latency-dependence of distractor-elicited attraction of attention versus distractor-elicited suppression of attention might have created the saccade endpoint effects of the present study.

5. Conclusion

In conclusion, in line with a stimulus-driven capture effect of subliminal onsets, we found that unseen distractors delayed the execution of target-directed saccades. This finding nicely resonates with recent claims that subliminal onsets are special in that their capturing of attention is truly automatic (Fuchs, Theeuwes, & Ansorge, 2013; McCormick, 1997; Mulckhuyse & Theeuwes, 2010; Van der Stigchel, Mulckhuyse, & Theeuwes, 2009).

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