1-2021

Impaired Suppression of Attentional Capture near the Hands

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Impaired Suppression of Attentional Capture near the Hands

by

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A thesis presented to
The Graduate School
of Washington University in
partial fulfillment of the
requirements for the degree
of Master of Arts

January 2021
St. Louis, Missouri

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Acknowledgments

First and foremost, my sincere gratitude goes to my advisor Richard Abrams, who has devoted hugely in my research and my personal growth. Although he never failed to laugh at my awkwardness in reacting to his dry sense of humor, when it came to mentoring me on research he was recharged with overflowed patience and tolerance. The transition from college straight to graduate school once overwhelmed me with a mass of new techniques and choices of research topic. Fortunately, Richard was patient enough to guide me through my initial research projects in a hands-on manner. His wisdom and kindness gradually transformed me from a beginner to an intermediate player in attention research. I can now better outline my research interest, and am equipped with knowledge and passion for the journey ahead.

I also want to express my sincere appreciation to the other committee members, Julie Bugg and Wouter Kool, for the precious feedback and the inspiring questions they raised during the defense. Their input provided me with new perspectives on the research question.

I am thankful for my lab mate Kendra Smith for her company and help along the way. It is a blessing to have a “big sister” figure in the lab, who was always there to provide insight into my work.

Last but not least, I would not be able to make it without the unwavering support of my parents. Their unconditional love and acceptance repeatedly harbored me in the storms as well as filled me with courage to set sail again.

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January 2021

ABSTRACT OF THE THESIS

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Master of Arts in Psychological and Brain Sciences

Washington University in St. Louis, 2020

Professor Richard A. Abrams, Chair

Attention tends to be attracted to eye-catching stimuli, which, however, are not always helpful to look at, depending on the particular task. Recent findings demonstrated that attention to a salient but task-irrelevant distractor could be actively suppressed via a top-down process. In other research, increased scrutiny in visual inspection has been found in the near hand space, making it interesting to question, at the intersection of the two lines of research, whether the ability to ignore salient distraction would be compromised near the hands. Two experiments were conducted to test this idea. Experiment 1 compared the attentional allocation to a salient distractor near to and far from the hands during a visual search task. It was found that while attention to the salient distractor was less than that to a reference non-salient distractor when the hands were far, this pattern reversed when the hands were near, implying potential impairment in attentional suppression near the hands. Attention attracted to the salient distractor, interestingly, did not adversely affect performance on the main visual search task. However, instead of solely supporting the explanation of deficient top-down control of attention, the observed phenomenon could alternatively be caused by a boost in the bottom-up attentional capture near the hands, which, based on the findings of other research that suggested the extra caution in visual inspection near the hands, could be a reasonable concern. Experiment 2 was conducted to test

this possibility. Using a task that did not permit suppression of attention, the same amount of attentional capture by the distractor was observed across hand proximity conditions. These results demonstrate that the suppression of attention is impaired near the hands.

Chapter 1: Introduction

1.1 Suppression of Attentional Capture

You might not want to take more than a glance at each individual leaf among thousands of leaves in a bush, but a showy flower is likely to poke through the homogeneous green scene and grab your eye. Physically salient things, like a red flower standing out from a green bush, capture attention automatically through a bottom-up process (Corbetta & Shulman, 2002; Itti & Koch, 2001; Theeuwes, 1992, 2010). However, not all physically salient things are important to notice, and sometimes sparing limited attentional resources for them could distract people from their important task at hand. For example, at an airport's baggage screening station, the sudden lighting up of a staff member's cell phone screen could draw their attention from the computer monitor to the phone, which may lead to consequent missing out of some dangerous weapons that happen to be going through the X-ray at that moment. Therefore, it is important for people to be able to suppress attentional capture by eye-catching things that are, however, unhelpful to look at. Previous research has shown that with a clear task goal in mind, people are able to narrow down their focus to the specific target feature they are supposed to attend to, and resist the distraction by physically salient but task-irrelevant stimuli--a process referred to as the top-down control of attention (Anderson & Folk, 2010; Folk et al., 1992).

It was previously thought that attentional priority is solely determined by physical salience. For example, Jonides and Yantis (1988) observed that visual search was substantially enhanced when the target was characterized by an abrupt onset among other static non-target stimuli. Theeuwes (1992) had participants search for a shape or color singleton in an array, among which sometimes a distractor that was a singleton in another dimension appeared. He found that even if the distractor was not unique in the target-defining dimension, attention was nevertheless drawn to it due to its physical discriminability. This task was later known as the *additional singleton paradigm*. Abrams and Christ (2003) discovered that the change of state of a stimulus--from static to movement--also captured attention (also see Smith & Abrams, 2018). One common way to manipulate physical salience in these and other studies is to create visual discontinuity, such as a color singleton among an array of uniform colors (a static discontinuity; Theeuwes, 1992), or the abrupt onset of a distractor (a dynamic discontinuity; Jonides & Yantis, 1988; Remington et al., 1992; Yantis & Jonides, 1984). Visual discontinuities like these stand out from the scene and capture attention. Nowadays, however, researchers believe that bottom-up salience is not the only determinant of attentional allocation, and it is possible to ignore the salient features if they do not match the task goal that the observer bears in mind. It was previously known that in a visual search task, when the target identity is unclear, attention could be easily drawn by physically salient distractors--the abrupt onset of a distractor or a color singleton can capture attention. However, Folk et al. (1992) found that when participants were instructed to specifically look for a color singleton target, the sudden appearance of a distractor no longer attracted attention, since it did not match their top-down goal. Conversely, when participants were instructed to look for a target with an abrupt onset, a color singleton was no longer able to capture attention. These findings imply that stimuli out of the observer's attentional control setting induced by task demand, despite their salience, may not necessarily receive attentional priority.

Sawaki and Luck (2010) later hypothesized that the reason people are able to be exempt from attentional capture by salient distractors is that they actively suppress the intent to attend to them. In the *signal suppression hypothesis* they proposed, if physically salient stimuli are evaluated as mismatching the observer's goal in early processing, they could be subsequently suppressed and not attended to. Evidence supporting this claim includes event-related potential (ERP) studies. It was found that an inhibition-related component, *distractor positivity* (P_D; Hickey et al., 2009), was elicited in the situations where the interference by the presence of a singleton distractor on task performance was reduced (Burra & Kerzel, 2014; Eimer & Kiss, 2008; Gaspar & McDonald, 2014; Jannati et al., 2013; Sawaki & Luck, 2010, 2011). In behavioral studies, it was also observed that when the salient distractor appeared close to the target, participants' target detection performance was worse compared to when it appeared at a location far away from the target (Gaspar & McDonald, 2014; Jannati et al., 2013). Gaspelin, Leonard, and Luck (2015) recently provided more direct evidence supporting this hypothesis using a *capture-probe paradigm*. As its name implies, their experiment consisted of interleaved search trials that displayed occasional non-target color singletons in a visual search task that could capture attention, and probe trials that examined attentional allocation to individual search array items. On a search trial, participants searched for a shape target among an array of shapes while trying to ignore an occasional color singleton distractor, and reported the position of a dot on the target. On a probe trial, the display started with the same search array as that on a search trial, but shortly after the onset of the display, a letter appeared briefly on each of the shapes. In that situation, participants were instead supposed to recall as many letters as they could after the offset of the display. With this paradigm, if performance is better for probe letters at the location of the color singleton than that of a non-singleton distractor, it is suggested that the color singleton received attention. On the contrary, if performance is worse for probe letters at the location of the color singleton than that of a non-singleton distractor, it alternatively suggests that attentional capture by the color singleton was suppressed. It was found that the letters at a color singleton location were recalled less accurately than those at a non-singleton distractor location, reflecting below-baseline attentional allocation to the color singleton. This research provided direct evidence for people's active suppression of capture by salient but goal-mismatching stimuli.

1.2 The Effect of Hand Proximity on Visual Attention

The way stimuli in the environment are processed in the human brain can be malleable and contingent on individuals' physical capabilities (Gibson, 1979; Glenberg et al., 2013; Wilson, 2002). Bearing a large variety of acts and labors, human hands and their distance to surrounding objects are important considerations in interpreting the environment. Objects near the hands are in close proximity to the body and are therefore more likely to pose a threat to the organism (e.g., a snake) than those far from the hands. Being the immediate candidates for action, objects near the hands are also more likely to be used as potential tools (e.g., a long stick as weapon). These facts make it reasonable for a range of adaptive functions to develop that enable differential processing for stimuli near the hands. Converging with the idea, a large amount of research has shown that perceptual and cognitive processing is altered in the near hand space (Abrams et al., 2008; Agauas et al., 2020; di Pellegrino & Frassinetti, 2000; Reed et al., 2006; Schendel & Robertson, 2004), which is referred to as the *hand proximity effect*. Schendel and Robertson (2004) accidentally discovered that a patient with a brain lesion that consequently led to visual neglect in the left visual field had his vision partially restored when extending his left hand towards the direction of the previously neglected visual field. Abrams et al. (2008) manipulated participants' hand proximity to stimuli by having them place their hands either on the sides of a video monitor or on their laps during two blocks of the same experiment. The two posture manipulations were separately referred to as the hands-near and the hands-far conditions. Using a visual search task, they found that as the number of stimuli increased, the corresponding increase in search time was more drastic for the hands-near condition than for the hands-far condition, suggesting that participants searched the display at a slower rate when their hands were near. Abrams et al. (2008) examined the inhibition of return phenomenon under different hand proximities, and found a reduced magnitude near the hands, which explained the slowed search rate near the hands as delayed disengagement of attention from each item. This reflected a prolonged inspection time for each item, indicating more cautious and thorough analysis for stimuli in the near hand space due to their potential importance.

A number of other visual features have been found to be affected by a proximal hand, such as delayed switch of attentional scope (Davoli et al., 2012), improved visual short-term memory (Tseng & Bridgeman, 2011), biased figure-ground segregation (Cosman & Vecera, 2010), impaired object-based attention (Suh & Abrams, 2015), enhanced magnocellular processing and subsequent increase in temporal acuity and sensitivity to low spatial frequency information (Abrams & Weidler, 2014; Gozli et al., 2012). The common idea shared across these findings is that due to the evolution-imposed perspective that objects near the hands are of greater survival significance to individuals, people would therefore treat them with more caution and attentional priority.

Corresponding to the fact that objects near the hands likely require further treatment, recent evidence suggests that higher-order executive function that facilitates situation-based decision making and fast responding is enhanced near the hands. Davoli et al. (2010) had participants performed a color Stroop task (Stroop, 1935) separately with their hands near to and far from the display, and found dramatically reduced Stroop interference in the hands-near condition than in the hands-far condition. Fast and accurate responding in a Stroop task reflects inhibition of the dominant but task-irrelevant semantic processing, and the improved performance near the hands indicated increased inhibitory control, which is one of the basic processes of executive function. Weidler and Abrams (2014) later demonstrated similar enhancement in cognitive control separately in a flanker task experiment and a task-switching experiment. These findings imply that having the hands near the display could help an individual better concentrate on the current task while ignoring irrelevant distractions.

Chapter 2: Overview of Present Study

Based on the review of the literature, it can be seen that research in both the top-down control of visual attention and the hand proximity effects are well established, but it remains unknown whether the suppression of attentional capture by physically salient but task-irrelevant stimuli is different near the hands. If there is any difference, either a more robust or a reduced degree of suppression seem possible in the near hand space. On the one hand, although it might be considered task-irrelevant, a physically salient distractor that stands out might be instinctively perceived as signaling potential abnormality or danger that needs extra attention. According to the evidence supporting prolonged visual inspection (Abrams et al., 2008), delayed disengagement of attention (Abrams et al., 2008; Vatterott & Vecera, 2013), and enhanced visual memory encoding near the hands (Tseng & Bridgeman, 2011), due to their potential importance, objects near the hands should involuntarily receive more caution and preferential examination. With the increased scrutiny, salient distractors in the near hand space might be able to escape suppression, and nevertheless capture attention, even if their presence could be ignored when displayed far away from the hands. On the other hand, findings on enhanced cognitive control near the hands (Weidler & Abrams, 2014) alternatively imply that people might have better attentional control on the display near their hands, and could consequently reinforce the top-down goal to focus on target-related features, as well as to inhibit distraction by eye-catching but goal-mismatching distractors.

The mechanisms underlying the two possible outcomes--preferential attentional selection and cognitive control--reflect different stages of processing. Attentional selection based on bottom-up information involves early sensory filtering of physical information soon after it is registered, whereas cognitive control is almost by definition a later process. The efficient completion of a visual search task under distraction requires both aspects of abilities. On the one hand, the screening and rejection of bottom-up salience signaled by a singleton should happen in early visual processing. On the other hand, reinforcing the top-down goal and prioritizing target searching involve higher order cognitive processing. This complicated nature of the task suggests either hypothesized outcome could be likely. In addition, despite the multiple visual effects that have been found to be altered near the hands, it is also possible that hand proximity plays no role in the suppression of attention.

The present study aims to provide an answer to the equivocal question by experimentally examining whether hand proximity has any effect on the suppression of attentional capture. To achieve this goal, participants were tested with a capture-probe paradigm that examines the suppression of capture with their hands near to or far from the display in a within-subject design. If the inspection of stimuli near the hands follows a survival-serving rule and attention is involuntarily prioritized for danger-signaling stimuli, the salient distractors would escape suppression and receive attention. Alternatively, if cognitive control is enhanced near the hands, as the capture-probe paradigm is a similar task to a Stroop or flanker task that requires the inhibition of unhelpful information, the suppression of salient distractors should conversely be greater.

Chapter 3: Experiment 1

Experiment 1 examined whether there was any difference in the suppression of attentional capture by salient but task-irrelevant distractors near the hands, and if so, the direction of change. To do this, the capture-probe paradigm was combined with a hand proximity manipulation. Each participant separately placed their hands either at the sides of the monitor (the hands-near condition) or on their laps (the hands-far condition). The experiment was similar to Gaspelin et al.'s original paradigm (2015), except for some modifications to the task and the means of response that made it more suited to responding when people were assuming required hand positions.

3.1 Method

3.1.1 Participants

Twenty-five undergraduate students at Washington University in St. Louis were recruited to participate in the experiment and were reimbursed with course credits. Informed consent was obtained from each of them. All the participants went through a pre-experiment screening to ensure that they meet normal or corrected to normal visual acuity, and normal color vision requirements. Previous studies using a capture-probe paradigm (Gaspelin et al., 2015, 2017) suggested that a sample size of 24 or more would yield ample power.

3.1.2 Apparatus

The setup of the experiment is demonstrated in Figure 1. The experiment was programmed with PsychoPy software (PsychoPy 3.2.4; Peirce, 2011). The stimuli were displayed on a 23-inch monitor that was rotated to a less common portrait view. This let participants hold the shorter edge of the monitor (32.3 cm) in between their two hands in the hands-near condition, which guaranteed the proximity of the hands to stimuli. Responses were collected using two 6.5 cm diameter response buttons. In the hands-near condition, the buttons were attached to the left and right edges of the monitor, aligned with the midpoint of the longer edge. In the hands-far condition, the buttons were moved to the two end caps of a 7.6 cm diameter PVC tube that was of the same length as the shorter edge (32.3 cm) of the monitor, and was held by the participants on their laps. A chinrest (not shown in the figure) was used to ensure that the viewing distance remained constant at 57 cm across hand proximity conditions.

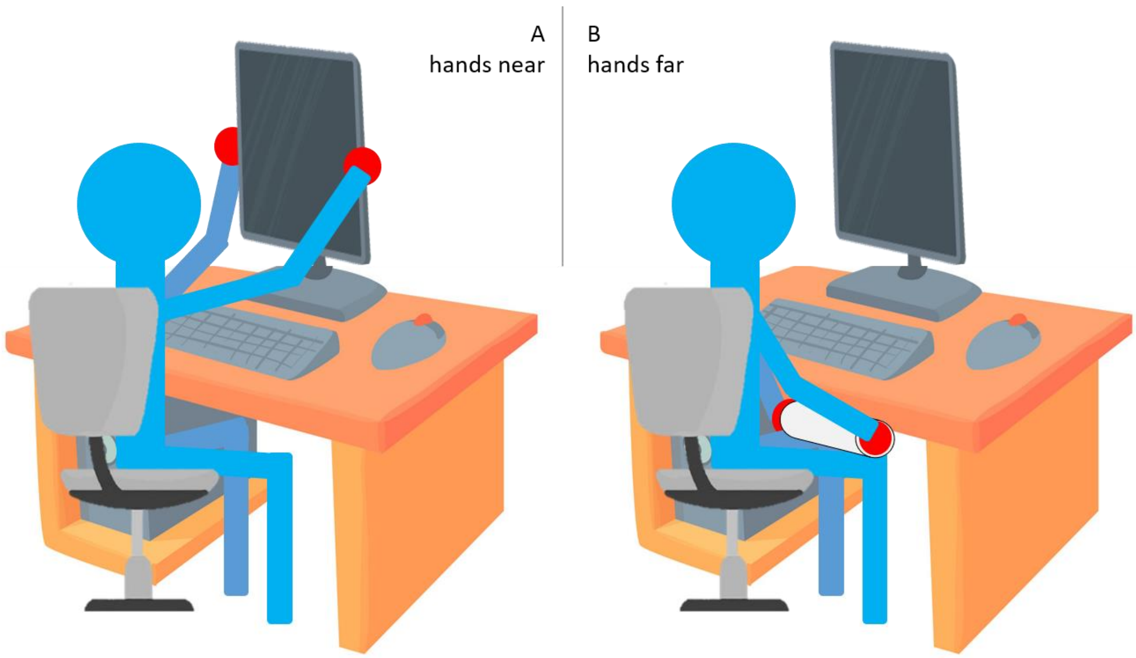

Figure 1. Illustration of experiment setup in hands-near (A) and hands-far (B) conditions. The red circles represent the response buttons. The monitor was rotated to portrait mode. In the hands-near condition, participants responded by pushing the buttons on the two sides of the monitor along the longer edge. In the hands-far condition, participants responded by pushing the buttons on the two end caps of a PVC tube placed on their laps.

3.1.3 Stimuli and procedure

Examples of the sequence of events are presented in Figure 2. The experiment consisted of intermixed search trials and probe trials. All stimuli were presented against a black background. At the beginning of a search trial, a white fixation cross (0.7°×0.7°) was presented at the center of the screen for 1,000 ms. Following that, a search array of 4 shapes appeared along the circumference of an invisible circle with a radius of 4.5°, at the 12, 3, 6, and 9 o'clock positions, centered on the screen. It consisted of a circle (0.9°×0.9°), a diamond (0.8°×0.8°), a square (0.8° ×0.8°), and a hexagon (0.8°×0.8°). The target shaped was either a circle or a diamond, for different participants. On a *singleton absent* trial, all the four shapes were in the same color, green or red for different participants. On a *singleton present* trial, one of the non-target shapes was in a unique color, and the array was either one red shape among three green shapes, or one green shape among three red shapes. On each of the shapes, there was a short black line segment (0.05°×0.3°) tilted 45° randomly to the left or right. Participants were required to find the known target shape and report the tilting direction of the line in it as quickly and accurately as they could, by pushing the button held in their left or right hand. The search display remained on the screen for 2,000 ms or until response. After the offset of the search display, if the participant had pushed a wrong button, an "Incorrect response!" error message was displayed for 500 ms with a simultaneous error tone at 150 Hz. If no responses were detected, a "Too slow!" error message and an error tone were given. Then followed the next trial.

A probe trial began with the same search array as that on a search trial with the same singleton present or absent conditions, except that the display only lasted for 200 ms. Directly following the offset of the search array, a letter probe that was either an "H" or an "S" (0.8° in height) briefly flashed for 30 ms at the location of one of the shapes in the previous scene, and was then followed by a blank screen. In this situation, the search array was presented too briefly for the participants to finish the search. They were instead instructed to report the identity of the briefly displayed letter by pushing the left button for an "H" and the right button for an "S". A 1,500 ms blank screen after the offset of the letter was used as the time window for response entry, and the trial ended after its elapse or when the participant responded. If the participant pushed the wrong button during the blank screen display, an "Incorrect response!" error message was displayed for 500 ms with a simultaneous error tone at 150 Hz. If no responses were detected, a "Too slow!" error message and an error tone were given.

In the hands-near condition, participants placed their hands at the two sides of the monitor, and responded by pushing the two buttons previously attached to that position by the experimenter. In the hands-far condition, the two buttons were attached to the two ends of a PVC tube that was placed on the participants' laps.

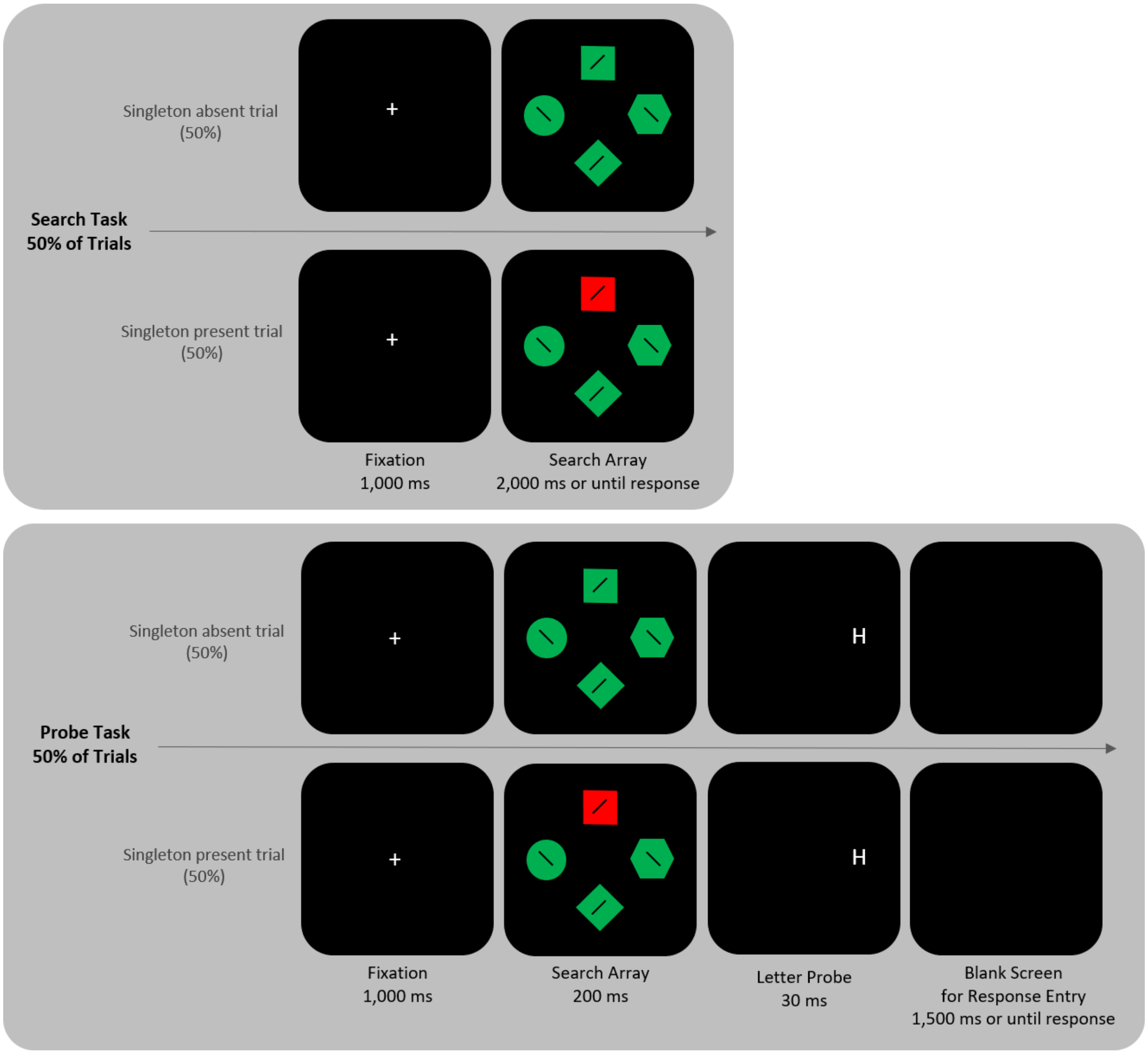

Figure 2. Illustration of trial events on a search (top panel) and a probe (bottom panel) trial in Experiment 1. The experiment consisted of intermixed search trials and probe trials. On a search trial, participants were required to search for a known shape target (circle for half of the participants, diamond for the other half), and report the line orientation in it. On a probe trial, the search array was briefly presented and then replaced with a briefly displayed probe letter (H or S) at the location of one of the shapes in the previous scene. Participants were required to report the identity of the letter. Within a search array, the shapes were in a uniform color on singleton absent trials, while on singleton present trials one of the non-target shapes was in a different color. The color assignment was counterbalanced across subjects. For half of them, the uniform color was green, and the singleton color was red (as in the illustration); for the other half, the assignment was reversed.

3.1.4 Design

The experiment consisted of an equal number of search trials and probe trials. In the search array that was presented on a search trial and at the beginning of a probe trial, the target shape was equally likely to appear at each of the four possible locations. The target identity was counterbalanced across subjects, which was defined as a circle for half of the participants, and a diamond for the other half. There were an equal number of singleton absent trials and singleton present trials. The color assignment to the target and the singleton distractor was counterbalanced across subjects. For half of the participants, the uniform color was green and the singleton color was red; for the other half, the mapping was reversed. These allowed the target identity fully counterbalanced to be a green circle, a green diamond, a red circle, and a red diamond separately across randomly assigned four groups of participants. On a probe trial, the probe letter was equally likely to appear at any of the four stimulus locations. Probe letters that appeared at the target, the non-singleton distractor, and the singleton distractor locations are separately referred to as the *target probe,* the *non-singleton distractor probe*, and the *singleton distractor probe*. The factors of trial type (search trial vs. probe trial), and singleton presence (present vs. absent) were randomly varied independently, such that each participant received approximately an equal number of trials in each of the 4 possible combinations of these conditions.

Hand proximity was manipulated using a within-subject design. The experiment was split into two halves, during each of which the participant maintained either the hands-near or hands-far posture. The order of the two postures was counterbalanced across subjects. Participants completed 24 practice trials and 8 blocks of 108 test trials (864 trials total).

In summary, hand proximity (near, far) and singleton presence (absent, present) were independent variables on both search and probe trials. The additional independent variable on probe trials was probe location (target probe, non-singleton distractor probe, singleton distractor probe). The dependent variables were participants' reaction time and accuracy in completing corresponding tasks.

3.2 Results

Three participants were removed from analysis, separately due to (1) a high error rate (more than 3 SD above the mean error rate for all participants) in the search task, (2) a high error rate in both the search and the probe tasks, and (3) technical issues that caused program crashing during the experiment, leaving the data from 22 participants submitted to analyses.

Data trimming was performed on individual participant's data. Search trials with correct responses were sorted into the four singleton presence (present, absent) × hand proximity (near, far) cell combinations, and probe trials with correct responses were sorted into the ten singleton presence (present, absent) × hand proximity (near, far) × probe location (target probe, non-singleton distractor probe, singleton distractor probe) cell combinations. (Note that the singleton distractor probe could only occur under condition of singleton presence, making the different levels of the three variables not fully crossed with each other.) For each participants' data, means and standard deviations of RTs within each cell condition were calculated. Trials with RTs above or below 2 standard deviations from the mean RT of that cell were excluded from the RT analysis.

3.2.1 Search Task

Reaction Time

Figure 3 (left panel) shows mean search task RT as a function of singleton presence and hand proximity condition. The trimmed search task RT data was submitted to a 2 (singleton presence: present, absent) × 2 (hand proximity: near, far) repeated measures ANOVA. There was a significant main effect of singleton presence, $F(1, 21) = 10.986$, $p = .003$, $\eta^2_p = .343$. Search task responses were significantly faster by 24 ms on singleton present trials (940 ms) than on singleton absent trials (964 ms). This suggests that the presence of a color singleton did not cause a performance cost, but actually benefited the task to an extent. The main effect of hand proximity was not significant, $F < 1$. Responses in the hands-far condition (945 ms) were slightly faster than those in the hands-near condition (958 ms), but the difference was not big enough to reach significance. The interaction between singleton presence and hand proximity was not significant either, $F(1, 21) = 1.614$, $p = .218$, $\eta^2_p = .071$.

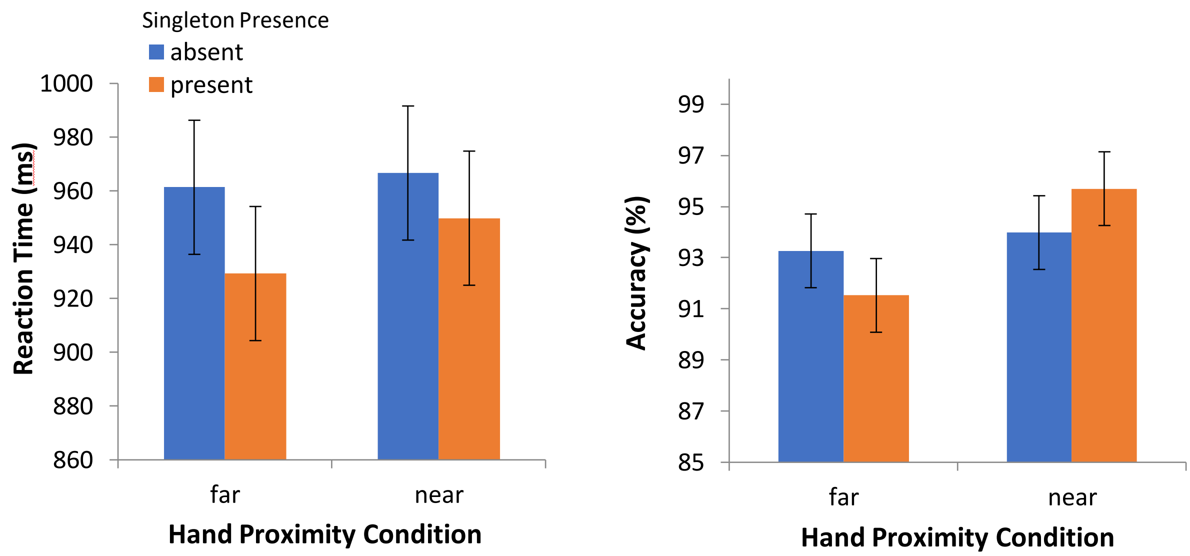

Figure 3. Mean RT (left panel) and accuracy (right panel) of the search task in Experiment 1. Error bars indicate standard errors.

Accuracy

Figure 3 (right panel) shows mean search task accuracy as a function of singleton presence and hand proximity condition. The same two-way repeated measures ANOVA was conducted on search task accuracy. The main effect of singleton presence was not significant, $F < 1$: Participants were equally accurate in the search task on singleton present trials (93.6%) and singleton absent trials (93.6%). The main effect of hand proximity was also not significant, $F(1, 21) = 2.391$, $p = .137$, $\eta^2_p = .102$: Participants were equally accurate in the hands-near condition (94.8%) and in the hands-far condition (92.4%). Interestingly, the interaction between singleton presence and hand proximity was significant, $F(1, 21) = 11.187$, $p = .003$, $\eta^2_p = .348$. In the hands-near condition, responses were significantly more accurate when the color singleton was present, $t(21) = 2.277$, $p = .033$, however, in the hands-far condition, responses were significantly less accurate when the color singleton was present, $t(21) = 2.626$, $p = .016$.

3.2.2 Probe Task

As mentioned earlier, since the singleton distractor probe could occur only in the singleton present condition, the levels of the three independent variables were not fully crossed with each other, and thus cannot be analyzed in one ANOVA. To this end, two separate ANOVAs were done. The first one served the main purpose of the study, which included only the singleton present condition, and compared probe discrimination performance for the singleton distractor probe to the baseline non-singleton distractor probe, across hand proximity conditions. The second ANOVA covered the other factors (singleton absent condition and target probe location) that were not pertinent to the purpose of the study but were necessary indicators for the effectiveness of the experimental design. The same two separate analyses were used by earlier researchers (Gaspelin et al., 2015), except that in the current study hand proximity was included as an additional independent variable into each analysis.

Reaction Time

Figure 4 shows mean probe task RT (top panels) as a function of singleton presence and hand proximity condition. In order to examine the attentional capture effect of the color singleton, letter discrimination for the non-singleton distractor probe and the singleton distractor probe were compared. Probe task RTs on singleton present trials were submitted to a 2 (probe location: non-singleton distractor, singleton distractor) × 2 (hand proximity: near, far) repeated measures ANOVA. The results showed that there was a marginally significant main effect of probe location, $F(1, 21) = 3.825$, $p = .064$, $\eta^2_p = .154$. Responses to the non-singleton distractor probe (699 ms) were 13 ms faster than those to the singleton distractor probe (712 ms). This indicates that the attention to the color singleton was slightly less than that to the non-singleton distractor as measured by RT, implying a certain degree of attentional suppression of the color singleton across hand proximity conditions. However, neither the main effect of hand proximity, nor the interaction between hand proximity and probe location was significant, Fs < 1.

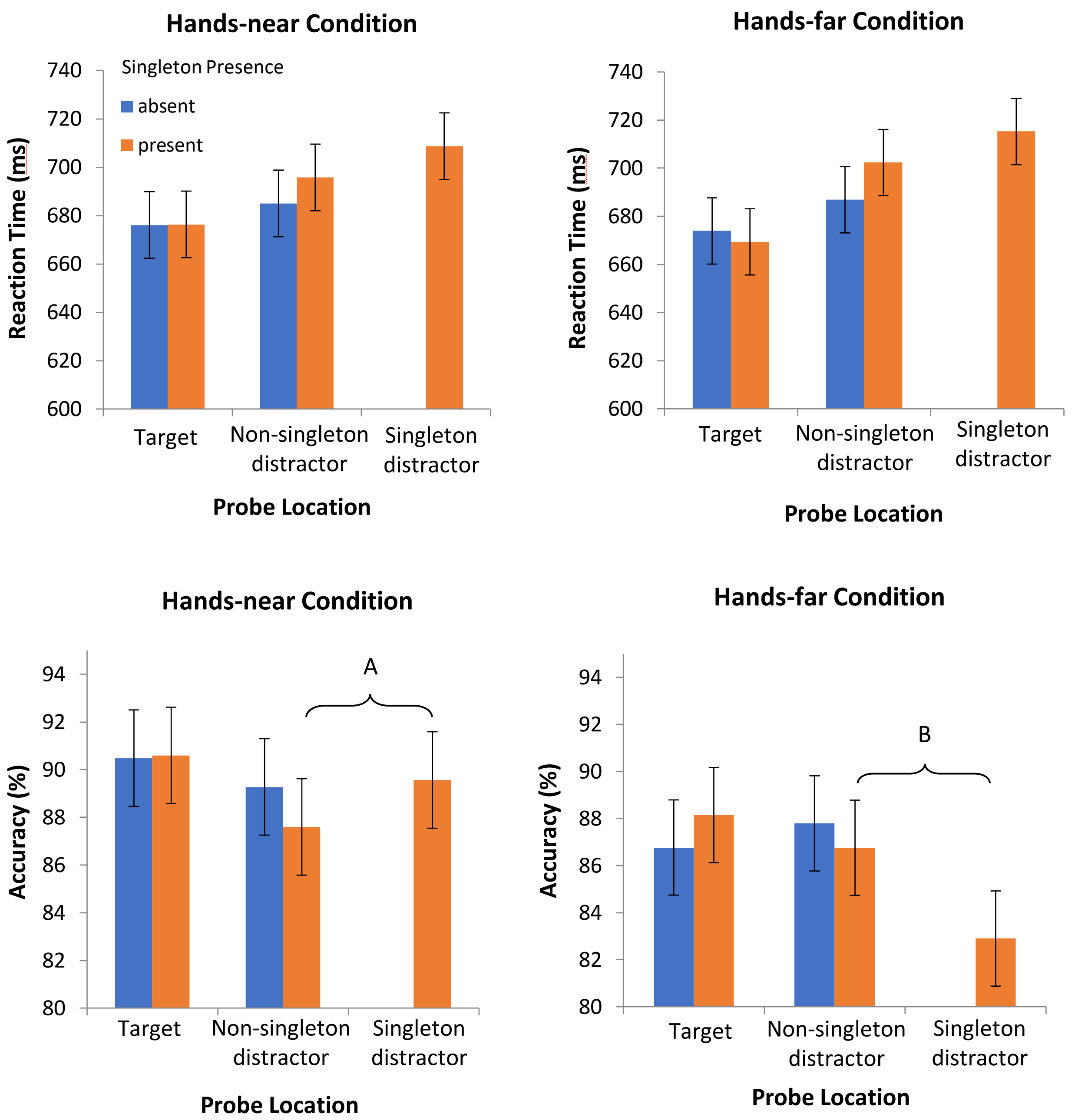

Figure 4. Mean RT (top panels) and accuracy (bottom panels) separately for the hands-near (left panels) and hands-far (right panels) conditions of the probe task in Experiment 1. Error bars indicate standard errors. The bars labeled A and B (bottom panels) are the critical pairs of comparison in accuracy between the non-singleton distractor probe and the singleton distractor probe.

In order to verify the effectiveness of the experimental design and for the completeness of data report, the effect of the singleton presence conditions and their interaction with the other factors were also analyzed. With the singleton distractor probe not being a possible case when the singleton was absent, the probe location levels included in the analysis were limited to the target probe and the non-singleton distractor probe. A 2 (probe location: target, non-singleton distractor) × 2 (singleton presence: present, absent) × 2 (hand proximity: near, far) three-way repeated measures ANOVA was conducted on probe task RT. There was a significant main effect of probe location, $F(1, 21) = 14.453$, $p = .001$, $\eta^2_p = .408$. Responses to the target probe (674 ms) were 19 ms faster than those to the non-singleton distractor probe (693 ms). The main effect of singleton presence was not significant, $F(1, 21) = 3.242$, $p = .086$, $\eta^2_p = .134$. Responses on singleton present trials (686 ms) and on singleton absent trials (680 ms) did not differ from each other. The main effect of hand proximity was not significant either, $F < 1$. Participants responded equally fast when their hands were near to (683 ms) or far from (683 ms) the display. Interestingly, the interaction between probe location and singleton presence was significant, $F(1, 21) = 4.652$, $p = .043$, $\eta^2_p = .181$. Post hoc t-tests showed that responses to the non-singleton distractor probe were significantly slowed down by the presence of a color singleton distractor, $t(21) = 2.909$, $p = .008$. Conversely, responses to the target probe were slightly but not significantly faster when a color singleton was present, $t(21) = 0.447$, $p = .660$. This implies that attention to the non-singleton distractor was more vulnerable to distractor presence, while attention to the target was relatively unaffected by the presence of a distractor. Besides those, none of the two-way interactions between probe location and hand proximity, singleton presence and hand proximity, or the three-way interaction between probe location, singleton presence, and hand proximity was significant, Fs <1.

Accuracy

Figure 4 shows mean probe task accuracy (bottom panels) as a function of singleton presence and hand proximity condition. The same set of analyses was performed on probe task accuracy data. A 2 (probe location: non-singleton distractor, singleton distractor) × 2 (hand proximity: near, far) repeated measures ANOVA was conducted on probe task accuracy. Interestingly, the results showed no significant main effect of probe location, $F < 1$. Unlike in the RT analysis, accuracy in probe discrimination at the non-singleton distractor probe (87.2%) and the singleton distractor probe (86.3%) did not differ from each other. The main effect of hand proximity was not significant either, $F(1, 21) = 2.564$, $p = .124$, $\eta^2_p = .109$. Participants were equally accurate in probe discrimination when their hands were near to (88.6%) or far from (84.9%) the display. Crucially, the interaction between probe location and hand proximity was significant, $F(1, 21) = 4.515$, $p = .046$, $\eta^2_p = .177$. Post hoc t-test showed that in the hands-far condition (labeled B in Figure 4), participants were marginally significantly more accurate at discriminating the non-singleton distractor probe (86.8%) than the singleton distractor probe (82.9%), $t(21) = 1.943$, $p = .065$, which is consistent with the performance pattern in RT data, suggesting suppression of attention to the color singleton. However, in the hands-near condition (labeled A in Figure 4), this pattern was reversed. Participants there were instead somewhat more accurate at discriminating the singleton distractor probe (89.6%) than the non-singleton distractor probe (87.6%), $t(21) = 1.355$, $p = .190$. Thus, unlike in the hands-far condition, in the hands-near condition the color singleton received more attention than the non-singleton distractor, suggesting failed attentional suppression there.

To examine the effect of singleton presence on probe task performance, a 2 (probe location: target, non-singleton distractor) × 2 (singleton presence: present, absent) × 2 (hand proximity:

near, far) three-way repeated measures ANOVA was conducted on probe task accuracy. The main effect of probe location was not significant, $F(1, 21) = 2.332$, $p = .142$, $\eta^2_p = .100$. Accuracy for the target probe (89.0%) was slightly but not significantly higher than that for the non-singleton distractor probe (87.9%). The main effect of singleton presence was not significant, $F < 1$. Accuracy in probe discrimination was not affected by the presence (88.3%) or the absence (88.6%) of a color singleton distractor. The main effect of hand proximity was not significant either, $F(1, 21) = 1.816$, $p = .192$, $\eta^2_p = .080$. Participants were equally accurate at probe discrimination when their hands were near to (89.5%) or far from (87.4%) the display. None of the two-way interactions between probe location and singleton presence, $F(1, 21) = 2.267$, $p = .147$, $\eta^2_p = .097$, probe location and hand proximity, $F(1, 21) = 1.348$, $p = .259$, $\eta^2_p = .060$, singleton presence and hand proximity, $F < 1$, or the three way interaction between probe location, singleton presence, and hand proximity, $F < 1$, were significant.

3.3 Discussion

As the proximity of hands to stimuli in the hands-far condition is more similar to that when using a keyboard for responses, the results in the hands-far condition replicated that of the original study (Gaspelin et al., 2015). In the search task, responses were faster when a singleton distractor was present, though with a slight but nonsignificant lower accuracy. In the probe task, both RT and accuracy indicated better performance for the non-singleton distractor probe than the singleton distractor probe. These results again demonstrate participants' ability to suppress attentional capture by salient but task-irrelevant distractors under distal hands placement. However, under the proximal hands placement, this ability to suppress attentional capture seems to be altered. Although participants' search task performance was not interfered with by the singleton presence, in the probe task, while successful suppression was indicated by the higher accuracy for the non-singleton distractor probe than the singleton distractor probe in the hands-far condition, this pattern was reversed in the hands-near condition. When the hands were near the display, discrimination for the singleton distractor probe was conversely more accurate than for the non-singleton distractor probe, which suggests that the color singleton competed for more attention than the non-singleton distractor. This critical difference between the two hand proximity conditions implies that attentional suppression of salient distractors is impaired near the hands. The results are consistent with the hypothesis based on the survival-serving purpose underlying the processing of near-hand stimuli: Due to the special vulnerability of an individual's hands, stimuli in close proximity tend to receive increased caution. Though irrelevant to the current task, an eye-catching color singleton might be perceived as signaling potential abnormality or danger, and is consequently able to penetrate the filter of attention based on a top-down goal.

One caveat regarding this conclusion is that the search task results show a different impact of hand proximity on attention from the probe task results. Contrary to the apparent attentional prioritization of the color singleton near the hands shown in the probe task, the search task results showed that the presence of the color singleton nevertheless benefited performance in the hands-near condition in both RT and accuracy. However, in the hands-far condition both the probe and the search tasks suggest that the singleton was suppressed. This discrepancy between hands-near and hands-far conditions might be accounted for by two possible reasons. First, notably, it is suspicious that in the search task, the RT and the accuracy results went in different directions for the hands-far condition. The faster RT at the presence of a singleton distractor suggests no singleton presence cost, however, the lower accuracy in the same condition suggests the opposite conclusion. These different directions of results imply a potential speed-accuracy tradeoff in the hands-far condition. Second, there are essential differences between the search and the probe tasks by design that make what the two tasks measured not totally the same. By measuring probe discrimination performance at different stimulus locations, the probe task showed a spatial map of where attention was directed. Differently, lacking for such location-wise tracking, the search task only showed the general impact the presence of the singleton had on the primary task. From that it cannot be concluded that attention went or did not go to the singleton location, as there might be other factors that contributed to the result, such as that the presence of a color singleton that was never a target helped exclude one potential stimulus to inspect. More importantly, the ability to selectively monitor behavior and to facilitate the attainment of chosen goals in one primary task requires cognitive control. In the hands-near condition, in the search task both the RT and the accuracy measures indicated better performance when a singleton was present, which is consistent with the previous findings of the enhanced cognitive control near the hands (Weidler & Abrams, 2014). With good cognitive control, it is possible that even though participants did attend to the singleton in the hands-near condition, this did not adversely degrade search task performance. This suggests that higher-order cognitive control might be helpful for alleviating the consequence of attentional capture by the color singleton in completing subsequent task, though it did not facilitate suppression of capture.

Although the cross-over interaction between hand proximity and probe location in probe task accuracy provided good evidence supporting a reduced degree of attentional suppression near the hands, this conclusion might be subject to a possible alternative explanation. The observed performance at the location of the color singleton in fact represents a combined effect of its initial bottom-up attentional priority and the top-down suppression of attention. Therefore, as the probe task accuracy results showed that the color singleton received more attention than the non-singleton distractor probe, this could be either due to an impaired amount of attentional suppression, or alternatively due to more robust bottom-up attentional capture by a salient distractor if it appeared in the near-hand space, while the strength of suppression remained the same.

There has been only limited research looking at the bottom-up attentional capture effect near the hands, and existing evidence is only marginally pertinent to this purpose. For example, Vatterott and Vecera (2013) had participants search for a shape singleton under the distraction of an occasional color singleton while touching one side of the screen with their middle finger. The results suggested that when the color singleton appeared on the same side of the screen as the pointed finger, the RT cost was greater than when it appeared on the different side of the screen from the pointed finger, suggesting attentional capture by the distractor caused greater consequences when it was near the hands. However, there is a potential problem that might undermine the credibility of this result. Notably, participants in this study only touched the screen with one middle finger, which was essentially a very different body posture from the monitor-holding posture used in the present study that required the use of the palm side of both hands. Reed et al. (2010) compared the hand proximity effects caused by different parts of the hand, and found that the effects specifically occurred near the palm side of the hand, which was possibly because only objects facing the palm are immediate candidates for action. Alternatively, other evidence showed no effect of hand proximity on attention to bottom-up stimuli. For example, Abrams et al. (2008) examined the effect of hand proximity on the engagement and disengagement of attention to the sudden onset of an uninformative peripheral cue. It was found that only the disengagement of attention was slowed near the hands, but the engagement of attention was the same for the hands-near and hands-far conditions, which suggests attentional capture by the onset cue did not differ as a function of hand proximity. Given the limited existing evidence, Experiment 2 of the present study aimed to provide a more direct investigation on whether bottom-up attentional capture is different near the hands, in order to further examine if the results in Experiment 1 are indeed due to impaired suppression of capture near the hands, or due to more robust attentional capture by the singleton near the hands.

Chapter 4: Experiment 2

In order to test the alternative explanation—more robust bottom-up attentional capture near the hands, Experiment 2 used an *additional singleton paradigm* (Theeuwes, 1992). Participants performed a visual search task looking for a target defined not as a specific shape (as in Experiment 1) but as a unique shape among the array, whose identity changed randomly across trials. In the meantime, a color singleton occasionally appeared as a non-target distractor shape among the array. Therefore, both the target and the distractor shared the feature of being a singleton, albeit differently in terms of shape or color. Since the target identity was uncertain, it disallowed a clear top-down template to form, and participants were tuned to a *singleton detection mode* (Bacon & Egeth, 1994), rather than a *feature search mode*. Under the singleton detection mode, the suppression of singletons in other dimensions becomes impossible, making the color singleton able to capture attention (Theeuwes, 1992). In order to compare the extent to which the color singleton captured attention between the hands-near and hands-far conditions, the same hand proximity manipulation as that in Experiment 1 was used. If the strength of bottom-up attentional capture does not differ as a function of hand proximity, then the singleton presence cost should be at the same level for both the hands-near and hands-far conditions. Conversely, if hand proximity has an effect on bottom-up attentional capture, and if salient distractors are more likely to capture attention when they appear near the hands, then a greater singleton presence cost in performance should be observed in the hands-near condition. If the former outcome occurs, the possibility of stronger attentional capture near the hands would be ruled out. However, if the latter outcome occurs, then the observed effects in Experiment 1 should alternatively be attributed to a more robust initial bottom-up capture near the hands.

4.1 Methods

4.1.1 Participants

Since one of the highly possible outcomes supporting that bottom-up attentional capture does not differ as a function of hand proximity is a null effect, the study originally planned to recruit a total of 36 participants so as to increase the power to reliably conclude a potential null effect. Unfortunately, the unexpected outburst of the pandemic suspended the data collection. Up to this point, data has only been collected from 22 undergraduate students at Washington University in St. Louis. They all had normal or corrected to normal vision and normal color vision, and each provided informed consent.

4.1.2 Apparatus

The apparatus was identical to that of Experiment 1.

4.1.3 Stimuli, design, and procedure

Examples of the sequence of events are presented in Figure 5. The task in Experiment 2 was identical to that of Experiment 1 with two exceptions. First, unlike Experiment 1, all trials in Experiment 2 were search trials. Second, the search display consisted of either a circle among three diamonds, or a diamond among three circles for all participants, which varied trial by trial. Instead of looking for a known specific shape, participants were instructed to look for a unique shape among the array, which was equally likely to be a circle or a diamond. As in Experiment 1, on half of the trials, the four shapes were in the same color; for the other half of the trials, one of the non-target shapes was in a different color. The factors of target identity (circle vs. diamond) and singleton presence (absent vs. present) were randomly varied independently so that participants received an approximately equal number of trials in each of the 4 possible combinations. The other details of the task and the hand proximity manipulation were identical to that of Experiment 1. Participants completed 24 practice trials and 4 blocks of 108 trials each (432 total) across the two hand proximity conditions.

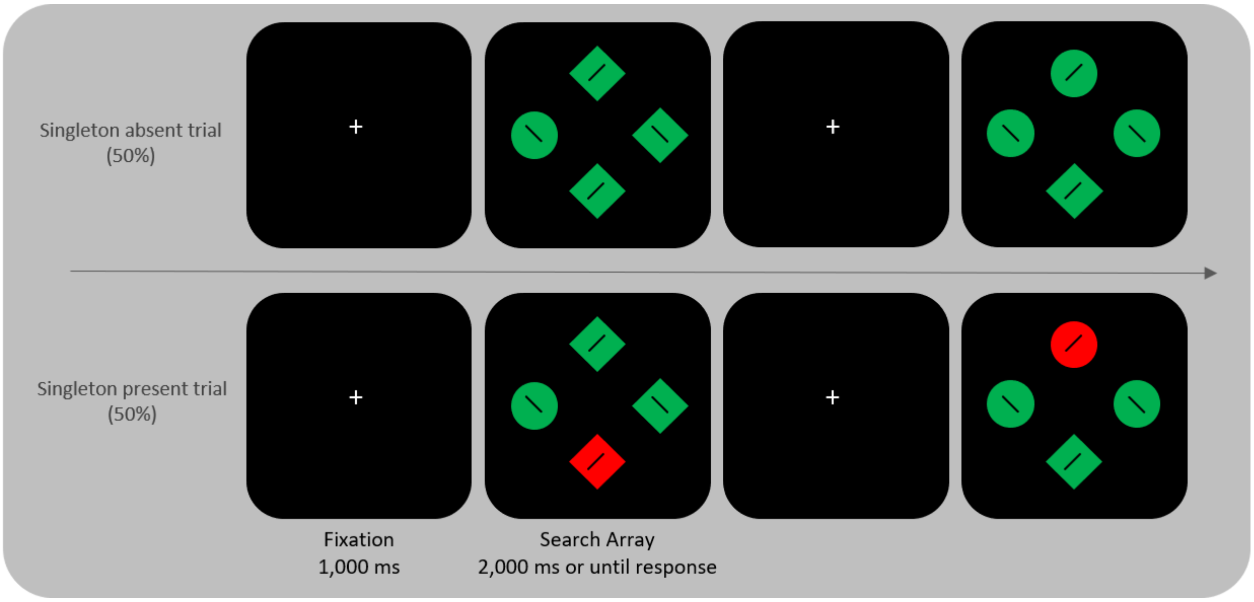

Figure 5. Illustration of trial events on singleton absent trials (top stream) and singleton present trials (bottom stream) in Experiment 2. The search array consisted of either one circle among three diamonds or one diamond among three circles, which varied trial by trial. The search target was defined as the unique shape in the array. On singleton absent trials, all four shapes were in a uniform color (red or green, counterbalanced across participants). On singleton present trials, one of the non-target shapes was in a different color. The figure shows two example consecutive trials each in the singleton absent and present conditions, where the target is a circle on the first trial, and a diamond on the following trial, and the singleton was shown in red among the green array.

4.2 Results

One participant was removed from analysis due to high error rate (more than 3 SD from the mean error rate), leaving the data from 21 participants submitted to analyses. Similar data cleaning as that in Experiment 1 was performed on individual participant's data. Trials with correct responses were sorted into the four singleton presence (present, absent) × hand proximity (near, far) cell combinations. For each participant's data, means and standard deviations within each cell condition were calculated. Trials with RTs above or below 2 standard deviations away from the mean RT of that cell were excluded from the RT analysis.

4.2.1 Classical Analysis

Reaction Time

Figure 6 (left panel) shows mean RT as a function of singleton presence and the hand proximity condition. The trimmed RT data was submitted to a 2 (singleton presence: present, absent) × 2 (hand proximity: near, far) repeated measures ANOVA. There was a significant main effect of singleton presence, $F(1, 20) = 6.193$, $p = .015$, $\eta^2_p = .072$: Responses were significantly slower by 64 ms on singleton present trials (1001 ms) than on singleton absent trials (937 ms). The main effect of hand proximity was not significant, $F < 1$. RTs in the hands-near condition (962 ms) did not significantly differ from those in the hands-far condition (976 ms). The interaction between singleton presence and hand proximity was not significant either, $F < 1$.

Accuracy

Figure 6 (right panel) shows mean accuracy as a function of singleton presence and the hand proximity condition. The same two-way repeated measures ANOVA was conducted on the accuracy data. The main effect of singleton presence was marginally significant, $F(1, 20) = 3.844$, $p = .053$, $\eta^2_p = .045$. Participants were 2.4% less accurate on singleton present trials (90.9%) than on singleton absent trials (93.3%). The main effect of hand proximity was not significant, $F(1, 20) = 1.988$, $p = .162$, $\eta^2_p = .023$. Participants were equally accurate in the hands-near condition (91.2%) and in the hands-far condition (92.9%). The interaction between singleton presence and hand proximity was not significant either, $F < 1$.

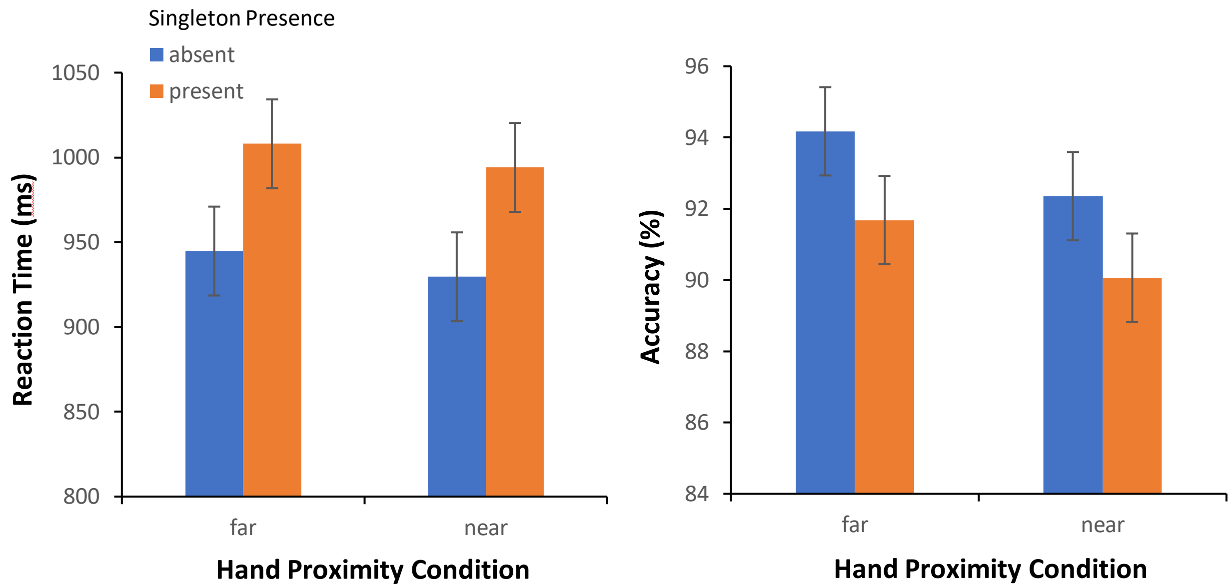

Figure 6. Mean RT (left panel) and accuracy (right panel) of Experiment 2. Error bars indicate standard errors.

4.2.2 Bayesian Analysis

The classical statistics for both RT and accuracy yielded non-significant outcomes in the critical analyses of the hand proximity effects. Since it is not possible to accept the null hypothesis using classical statistics, the non-significant results were further analyzed using Bayesian statistics. According to convention, Bayes factors BF_{01} with values greater than 1 provide evidence in favor of the H_0: Values ranging from 1 to 3 provide anecdotal, from 3 to 10, moderate, and above 10, strong evidence. Conversely, Bayes factors BF_{01} with values less than 1 provide evidence in favor of the H_1: With values from 1/3 to 1 providing anecdotal, from 1/10 to 1/3, moderate, and below 1/10, strong evidence.

Reaction Time

A 2-way Bayesian repeated measures ANOVA was conducted to quantify the evidence in favor of H_0, with singleton presence and hand proximity as the independent variables, and RT as the dependent variable (JASP Team, 2016, Version 0.12.2). The results showed that the Bayes factor BF_{01} for the main effect of singleton presence was .003, suggesting strong evidence in favor of H_1, which is consistent with the significant outcome yielded in the classical ANOVA that reveals a performance cost due to singleton distractor presence. The Bayes factor BF_{01} for the main effect of hand proximity was 2.966, according to convention which suggests anecdotal to moderate evidence for the absence of the effect. The Bayes factor BF_{01} for the interaction between singleton presence and hand proximity was 3.091, which suggests moderate evidence for the absence of an interaction effect.

Accuracy

The same Bayesian repeated measures ANOVA was conducted on accuracy. According to the results, the Bayes factor BF_{01} for the main effect of singleton presence was .067, suggesting strong evidence in favor of H_1, which is consistent with the marginally significant accuracy cost in the classical analysis. The Bayes factor BF_{01} for the main effect of hand proximity was .561, which suggests anecdotal evidence in favor of H_1, the presence of an effect. The Bayes factor BF_{01} for the interaction between singleton presence and hand proximity was 3.276, which suggests moderate evidence for the absence of an interaction effect.

4.3 Discussion

With attentional suppression, in the search task of Experiment 1 the presence of the color singleton did not bring a performance cost. On the contrary, by eliminating the possibility of suppression with the additional singleton paradigm, Experiment 2 showed a significantly prolonged RT and a marginally significantly reduced accuracy in the presence of a color singleton. These performance costs suggest that attention was involuntarily drawn to the distractor in the search for the target, which confirms the effectiveness of the experimental manipulations in the additional singleton paradigm. The critical result was the absence of a significant interaction between singleton presence and hand proximity in either RT or accuracy, which indicates no effect of hand proximity on the degree of attentional capture by the salient distractor. Despite the limited sample size, based on further Bayesian analyses, the two non-significant results nevertheless both presented moderate evidence in favor of the true absence of the effect. Given that, the null hypothesis was accepted, and it could be concluded that the initial bottom-up attentional capture does not differ as a function of hand proximity. This excludes the alternative explanation for Experiment 1, and suggests instead that the observed increase in attentional allocation to the color singleton near the hands observed there cannot be explained by a boost in the initial capture, but was indeed due to the impaired suppression of attention near the hands.

One item worthy of further interpretation is that in the classical analysis for accuracy, there was no significant main effect of hand proximity, however the Bayesian analysis alternatively demonstrated anecdotal evidence in favor of H_1. This discrepancy between analysis outcomes can be explained by the fact that the classical statistics use a harsher standard to reject H_0 (confidence level = .95) than the neutral convention in Bayes statistics. Furthermore, the Bayes factor BF_{01} = .561 merely just passes the threshold to be considered as anecdotal evidence. Based on these, it could be seen that the size of the effect is too small to be considered as solid support of either hypothesis.

Chapter 5: General Discussion

It has recently been found that attention to salient but task-irrelevant distractors could be actively suppressed with a clear top-down goal in mind (Gaspelin et al., 2015, 2017). Meanwhile, a wide variety of visual effects have been shown to alter in the near hand space (Abrams et al., 2008; Cosman & Vecera, 2010; Davoli et al., 2012; Gozli et al., 2012; Suh & Abrams, 2015; Tseng & Bridgeman, 2011; Weidler & Abrams, 2014). It remained unknown whether the suppression of bottom-up attentional capture would be different near the hands. The present study combined the two lines of research and aimed to answer the joint question that could provide a deeper understanding for both fields. Using a capture-probe paradigm with additional hand proximity manipulations, Experiment 1 took an initial step to compare the attentional allocation to a color singleton distractor between hands-near and hands-far conditions. It was found that while attention to the distractor was successfully suppressed in the hands-far condition (as measured by the probe task), the distractor nevertheless received above-baseline attentional priority in the hands-near condition, suggesting possible impaired suppression of attention near the hands, though without a cost to the primary search task. Experiment 2 was subsequently conducted to test the alternative explanation that the attentional suppression was intact near the hands, but the results were instead caused by an increase in bottom-up capture by the distractor in the first place. Using an additional singleton paradigm, the same degree of attentional priority for the distractor was found both near to and far from the hands, which helps rule out the increased capture explanation and instead attributes the effect in Experiment 1 to impaired suppression near the hands.

Several other aspects of the results deserve further discussion. In the probe task RT results of Experiment 1, location-wise comparison showed that responses to the target probe were significantly faster than that to the non-singleton distractor probe, and responses to the non-singleton distractor probe was marginally significantly faster than that to the singleton distractor probe. The former reflects the top-down goal-driven target prioritization, the significance of which confirmed the effectiveness of the probe location manipulation. The latter demonstrates a certain degree of attentional suppression of the salient distractor overall across the hand proximity conditions. When considering the potential global effect of the presence of the color singleton, RT remained the same with or without the presence of a color singleton, indicating that the overall probe task performance was not disturbed by the salient distractor, which is consistent with the conclusion of the search task performance. However, a significant interaction between singleton presence and probe location implies some local effect of the color singleton. Whereas letter discrimination at the target location was intact or even slightly speeded in the presence of a color singleton, that at the non-singleton distractor location was slowed down due to the presence of a color singleton. This might be because only the target shape perfectly matched the top-down goal, and thus received prioritization and was protected from the disturbance of the color singleton. On the contrary, the non-singleton distractor shape lacked for enough goal-matching features, and was thus more vulnerable to distraction.

In the probe task of Experiment 1, the critical difference in performance between the hand proximity conditions was observed in accuracy but not in RT. In a time-pressured forced choice task, it is common that people trade speed for accuracy, therefore an effect emerging in either measure should theoretically be considered of equivalent potency. In our probe task results, there was no sign of a speed-accuracy tradeoff, which confirms the reliability of the sole difference in accuracy. In fact, our experiment by design pushed the effect more likely to emerge in accuracy. The extremely brief display of the probe letter (30 ms) made it no longer helpful for the participants to spend time working on the answers after its offset, but the accuracy of response could be drastically compromised if the letter did not receive attention during its brief presentation. Gaspelin et al.'s original study (2015) using the capture-probe paradigm had a letter recall task being the probe task, where accuracy was the only measure given the unlimited time for recall response entry, and the critical effect of attentional suppression similarly revealed in accuracy.

The survival-serving processing account in the near hand space predicted that due to elevated caution, participants could not help but attend to the salient distractor despite its task irrelevance. The enhanced cognitive control account predicted that with better inhibitory control, participants could resist the impulse to attend to the salient distractor. It turns out that, on the one hand, the impaired suppression of attention observed in the probe task is more in favor of the survival-serving function of stimulus processing near the hands. On the other hand, the search task results that showed that performance was not interfered with by the presence of a distractor are consistent with previous findings of enhanced cognitive control near the hands. One may wonder why the enhanced cognitive control near the hands was not reflected in the suppression of attention to the distractor. A possible explanation is that cognitive control reflects higher-order executive functioning that happens relatively late in stimulus processing, whereas the filtering of bottom-up attention as measured in the probe task is a fairly early step. According to the “filter” theory of attention (Broadbent, 1958), whether sensory inputs, such as perceived salience, could further enter higher-order cognitive processing is contingent on an initial evaluation of their physical features, that is when the decision of “select” or “suppress” is made. Therefore, the ability to suppress attentional capture reflects a basic sensory filtering mechanism, that is at an essentially different stage of processing from the more complicated abilities demonstrated in classical cognitive control tasks, such as semantic processing and cognitive flexibility. In the capture probe paradigm, in the face of the striking salience of a color singleton, participants could not help but view it as an alerting signal that should not be ignored. Due to the elevated scrutiny for stimuli near the hands, this perceived salience tended to penetrate the attentional filter and be selected for deeper analysis. However, even if participants' attention was indeed captured by the singleton distractor appearing near their hands, with enhanced cognitive control that facilitated selective attainment of chosen goals in one primary task, their performance on the search task was nonetheless unaffected. This critical difference in stage of processing measured by the search and the probe task explains why enhanced cognitive control was not reflected in the ability to suppress attentional capture, but alternatively revealed in the search task where more time was allowed for deeper processing.

To sum up, the present study found impaired suppression of attentional capture by salient distractors near the hands. Despite the impaired suppression, due to enhanced cognitive control near the hands, performance in the search task was not affected by the presence of a singleton, suggesting that attention can be directed to a distractor yet that may not interfere with the primary task. Yet this remains only a reasonable conjecture based on the results of the present study. Future research is needed to confirm the mechanism behind the proposed explanation. In addition, the impaired suppression near the hands discovered in the present study specifically refers to reduced control of the involuntary orienting of covert attention. Likewise, it would also be interesting to examine whether the control of overt eye movement is similarly affected by outreached hands. Following this idea, future study plans to use eye tracking technique and test whether the suppression of the tendency to look at salient but task-irrelevant distractors is different as a function of hand proximity.

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