Lokaverkefni til BS–prófs
í sálfræði

Do feature-based regularities of task irrelevant stimuli modulate attentional capture?

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Abstract

Visual attention serves the purpose of selecting relevant information while simultaneously filtering out irrelevant information, these functions can although be biased by bottom-up processing. We set out to uncover whether visual processing utilizes regularities in distractor features, on a trial-by-trial basis, to reduce attentional capture. A previous study by Chetverikov, Campana and Kristjánsson (2020) showed that subjects could quickly form an accurate internal representation of a complex bimodal distribution of distractor features in distractor rejection templates under conditions of large set-sizes. Based on these findings, we examined whether such functions could also explain distractor suppression under smaller set-size conditions. Using a visual discrimination task and a covert paradigm, we manipulated distractor presence and feature regularities of distractors within blocks. Feature regularities were bimodally distributed and were brought about using two feature values, in contrast with each other, with one feature value being more probable than the other. Data was then gathered from 14 subjects. The results revealed that attentional capture was present in our paradigm, but we found no support for the notion that this attentional capture was reduced by feature regularities in distractors. Additionally, we found no support for the notion that distractor templates were operating on accurate distractor input and deploying suppressive measures accordingly. Although purely speculative, we observed some trends indicating that habituation might be the underlying distractor processing mechanism at work under the conditions of our experiment.

Preface

This psychology B.sc thesis was written under the guidance of Árni Kristjánsson and Omer Daglar Tanrikulu as a part of a collaboration with David Pascucci. Omer Daglar Tanrikulu programmed the experiment and provided instructions on data gathering and analysis. I am very thankful for this opportunity to work with great scholars in the field. I would also like to thank Omer Daglar Tanrikulu for his help, patience, and availability for which I am ever grateful.

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The visual attention system, a limited capacity processing system, serves the task of choosing what information will be focused on and will later be used to guide behavior. But the attentional system also serves the function of detecting what information is irrelevant and should be discarded from further processing. The major factors that the attention is said to use in selecting what information is going to be used to guide our behavior are physical properties of stimuli in the environment, goals or knowledge of the task at hand and more recently hypothesized the attentional selection history (Theeuwes, 2019). The popular "Where is Waldo" makes a great example to explain how these factors can help us find the often well-camouflaged character. First of all, he often appears in a highly cluttered environment filled with different characters and objects, in all the magical colors of the rainbow. The physical properties of the search array make him hard to find, now imagine how easy it would be to find him if he was presented alone on the page with a white background. Secondly, our goals can also help us find him, or at least someone that resembles him. Before you open the book you see a large picture of how he looks like, his white and red striped clothes can help you find him more quickly or as many have probably experienced his identically dressed friend Wilma. Lastly, our history and time spent searching for him through multiple books might aid us when searching for him in the upcoming book next year. Intuitively it would seem highly adaptive if we could solely focus on relevant information, keeping the picture of Waldo in mind and quickly and efficiently finding him. On the other hand, it would also seem especially helpful if we had complete control over any distracting information deciding to not focus on anything but Waldo himself and seeing him pop out as he was there on a white background.

But how does visual attention accomplish the task of choosing the right information from the environment with regards to the task at hand and what information should be discarded? This question has been the spark of countless experimental paradigms, all giving valuable pieces of information to answer this question but integrating the information gathered from behavioral- and physiological data into a comprehensive theory has proven to be a difficult task. The highly influential feature integration theory of attention put forward by Anne Treisman (1980) explained how specific feature categories could be processed preattentive, in parallel, and across the visual field. She described how the processing of features across the visual field fed information to feature maps, which in turn fed information to a saliency map. According to the theory, to perceive and respond to objects, the features have to be bound together by the attention which could explain the differences seen in feature search and conjunction search (Treisman, 1982). Wolfe (1989) put forward a similar model named guided search, which added the possibility of facilitation or suppression through top-down bias on the processing of feature maps. Similar to Wolfe’s model is the contingent-capture model, which states that simply having a feature in mind speeds visual search for targets sharing that particular feature (VanderHeijden, 1996).

A general theory of visual attention called the Biased Competition theory tries to explain how visual attention accomplishes the task of minimizing distractor interference. The theory states that objects presented simultaneously in the visual field and their respective neuronal representations will interact and compete for further processing, thus attributing the inhibitory effects with regards to the outcome of the competition itself. The theory also states that their competitive interactions can be biased in favor of one or the other by many different neural mechanisms e.g. bottom-up mechanisms, top-down mechanisms, or even feature-based mechanisms (Kastner & Ungerleider, 2001). The selectivity of the relevant information has although generally been attributed to a dual mechanism, one that is excitatory and facilitates target processing and another that is inhibitory and suppresses distractor processing. Most research on the subject of selective attention has been done on the facilitative mechanism of target processing but in more recent years, attention has been brought to the possibility and importance of inhibitory mechanisms involved in distractor suppression (Theeuwes, 2019).

What makes the study of attention difficult is the fact that visual attention can be divided into three qualitatively different mechanisms: Spatial-, object-, and feature-based attention; that function simultaneously but also interactively (Kravitz & Behrmann, 2011). The main observed difference between these three mechanisms is that spatial attention modulates information concerning specific areas in the visual field due in part to the retinotopic mapping in the primary visual cortex (Brefczynski-Lewis, Datta, Lewis & DeYoe, 2009) while the feature- and object-based mechanisms can modulate feature- and object-based information regardless of its location in the visual field (Desimone & Duncan, 1995). Additionally, it is known that top-down and bottom-up processing in the brain both play an important role in attentional selective processes but to what degree, either of them influences selectivity has been up for debate (Katsuki & Constantinidis, 2014). Finally, the visual attention can be even further divided into covert and overt orienting systems which seem to rely on much of the same neural circuitry (De Haan, Morgan & Rorden, 2008). Covert orientation refers to the function of the attentional system to shift visual attention to a particular space, object or feature while the overt attentional system achieves the same task by orienting the eyes. Researchers often use covert attentional paradigms, by keeping the eye gaze fixed, to better understand functions and capabilities of the attentional system without its ability to adjust incoming information by the means of reorienting the eyes (Chen, & Cave, 2016).

Posner (1980) devised a covert paradigm to assess the ability of the visual system to shift attention. He measured response times, under different conditions with regards to two different cueing conditions. In his paradigm exogenous cues served the function of automatically drawing the attention of participants to a target by highlighting its location, resembling the effects of bottom-up processing. On the other hand, endogenous cues served the function of instructing participants with a centered arrow the location of a target, resembling the effects of top-down processing. Research using his paradigms and valid cueing conditions has firmly established the capabilities of the covert, and overt visual attentional system to facilitate processing, reduce response times to targets and increasing detection of near-threshold events (Bashinski & Bacharach, 1980).

Even though it is a well-known fact that the brain is capable of deploying inhibitory effects on neuronal activity, even in early visual processing as can be observed in the retina and the primary visual cortex (Hubel & Wiesel, 1962), early research on the distractor processing employed perhaps a healthy bit of skepticism to the possibility that attentional mechanisms utilize inhibitory control over task-irrelevant information. One possible reason for this skepticism might be the fact that it is hard to differentiate if the observed effects in behavioral experiments are due to target facilitation, nonattendance to distractors, active suppression of distractors, or some combination of these factors (Chelazzi, Marini, Pascucci & Turatto, 2019). Another possibility for this skepticism might be attributed to the effects observed in the Ironic Process theory or the white bear problem, which describes the counter-intuitive notion that actively trying to suppress certain thoughts or behaviors actually makes them more likely to surface (Wegner & Schneider, 2003).

In spite of the aforementioned complications, there are growing amounts of research on the subject of distractor processing, in particular feature-based inhibition. Some electrophysiological experiments have identified event-related potentials (ERP’s) which seem to reflect direct suppression of distractors. Hickey, Lollo, and McDonald (2009) conducted ERP experiments using a search array consisting of one target and one distractor, with the purpose of investigating whether the N2pc component (linked with the deployment of visual attention) could reflect multiple attentional mechanisms. They observed a novel ERP distractor positivity component (P_D) appearing contralateral to distractor location in the visual field, as a result, they reasoned that the attention acts on both target and distractor representations. Later research has linked this P_D component to a suppressive mechanism, which effectively reduces attentional capture of potentially distracting visual objects and especially under the conditions of a speeded response (Gaspar & McDonald, 2014). Even though the neural mechanisms underlying this P_D component are still poorly understood, it has sparked interest in further research on the topic of distractor processing.

Other researchers have used behavioral data to investigate the possibility of flexible top-down control over task-irrelevant features with the use of a template for rejection (Arita, Carlisle & Woodman, 2012) which was said to compliment earlier works of Wolfe and Horowitz (2004) stressing the critical importance of top-down mechanisms in feature-based visual search. Results from the experiment were promising and indicated that nontarget feature cues, that could reliably differentiate nontargets from targets, resulted in a more efficient visual search in comparison to a neutral cue. These feature-based interpretations of the results have since been criticized on the account that the organization of the search array allowed for the use of a tactic to quickly reduce the number of possible targets. Targets and nontargets were grouped together on each side of the search array, the nontarget cue allowed for quick attentional capture of the distractor group, followed by a rapid disengagement and thereby effectively reducing possible targets by half. Further investigation on this explanation of the effects found in this nontarget feature cueing experiment has confirmed the hypothesized tactic, naming it spatial recoding (Beck & Hollingworth, 2015). Other researchers using this cueing paradigm of nontarget features in hopes of finding a feature-based inhibitory mechanism have arrived at a similar conclusion, that it leads to spatial recoding. Moher & Egeth (2012) used a similar nontarget feature cueing paradigm but manipulated the stimulus onset asynchrony (SOA), they observed that when the SOA was short e.g. 100ms, reaction times to targets surprisingly increased in comparison to the neutral cue. This led them to conclude that in order for the distractor to be suppressed, the distractor must first be selected by attention and can then be disengaged from by means of spatial recoding. In general, the effects observed using this feature cueing paradigm can not be attributed to a feature-based inhibitory mechanism.

Some similarities of this interaction between spatial- and feature-based attentional mechanisms have also been observed in statistical learning when the cognitive system aggregates recurring information across experiences (Schapiro, Turk-Browne, Norman & Botvinick, 2016). In an additional singleton task experiment performed by Wang and Theeuwes (2018) they observed that a salient singleton distractor could have diminishing interference on visual search effectiveness, stemming from growing experience with both target and distractor features. Statistical regularities in distractor locations caused spatial suppression effects, high distractor probability locations led to less interference when occupied by a distractor but longer response times when occupied by the target. These results indicated a feature salience-based distractor suppression mechanism but on what information it precisely operated could not be inferred.

Trying to bridge this gap in the knowledge of distractor suppression Gaspelin and Luck (2018) tried to distinguish between possible sources of feature information, underlying suppression of task-irrelevant singletons, using a probing paradigm. They hypothesized that if this suppressive mechanism relied on feature-based information, there were three possible sources of information the system could draw on. The first and simplest possibility being information concerning first-order features, referring to specific feature values of a single object. The second being second-order features, which refers to information concerning the relationships among values within the first-order feature dimensions. And lastly on information gathered from a global-salience map, which is considered feature dimension-independent. In their experiment they unpredictably swapped the color of singletons and nonsingletons distractors, thus allowing for second-order feature information and global-salience information to be used but denying the use of first-order information due to the unpredictability of the distractor singleton color. The probe accuracy on spaces previously occupied by a singleton distractor did not differ from probes on spaces previously occupied by nonsingleton distractors which indicated that suppressive mechanisms of distracting information were not at work. This is in clear contrast with previous findings which showed robust suppression effects at singleton distractor locations during probing when the singleton feature was predictable. Leading them to conclude that this feature-based inhibitory mechanism relies on the predictability of first-order feature information in order to suppress distracting information.

These experiments are indicative of a feature-based inhibitory mechanism that utilizes information concerning features of distracting stimuli in order to reduce interference in visual search tasks. These experience effects have been attributed to both inter-trial priming and statistical learning, which both seem to effectively minimize distractor interference (Goschy, 2014). But an important question still remains on the subject, to what extent feature-based expectations influence distractor suppression irrespective of spatial regularities. Moorselaar, Lampers, Cordesius & Slagter (2020) conducted experiments where they manipulated feature and spatial-based properties of targets and distractors, using orientation as a feature. They observed similar proactive and generic spatial suppression effects in high-probability distractor locations as was observed in Wang and Theeuwes (2018) under the conditions of unpredictable distractor features. More importantly, they observed that the predictability of distractor features affected target and distractor processing in a different way. When distractors were predictable at the feature level, spatial-based suppression was attenuated. Distractor suppression was affected by feature regularities while target suppression was not. Inhibition of stimuli at a likely distractor location was dependent on the expectations about feature-defining properties of the distractors. These results undoubtedly represent a strong argument for a flexible but experience dependant and feature-based inhibitory mechanism. They described these functions with a pre-stimulus sensory template that suppresses distractors based on the predictability of their feature values. Additionally, they described how this mechanism is reliant on implicit learning mechanisms.

Chetverikov, Campana, and Kristjánsson (2020) studied how such distractor templates could operate in the visual system. They devised a clever paradigm that allowed them to assess how these templates could predict distractors, based on previous experience with distractor feature values. The distractors used in their experiment were multiple orientation bars scattered around the search display, and their feature values were drawn from a bimodal distribution. This allowed them to compare whether distractor templates could accurately represent the feature values of distractors or if they represent them by means of averaging. Their results revealed that the templates could accurately represent the bimodal distribution of features portrayed by distractor.

Distractor probability within an experimental block is an important context-dependent factor in distractor processing research (Chelazzi et al., 2019). Marini, Chelazzi, and Maravita (2013) tested reaction times on a speeded discrimination task while manipulating the probability of distracting trials within blocks. In doing so they could compare mean reaction times between blocks. Some blocks contained no distractors on their trials (pure blocks) while others had some fixed proportion of their trials containing distractors (mixed blocks). The mere possibility of an upcoming distractor had detrimental effects on the RT's in the discrimination task, as could be observed by comparing mean RT's on distractor absent trials between pure and mixed blocks. They called it filtering cost and argued that distractor filtering cannot be fully explained by recent trial history. They further hypothesized that this possibility of distraction leads to the activation of a system that reduces distractor interference. This active system would effectively reduce interference on distracting trials but would rely on scarce resources of the attentional system, leading to less efficient processing on trials when distractors were absent.

Geyer, Müller, and Krummenacher (2008) showed similar results in a study where they manipulated distractor probability. They made three distinct block types and manipulated the proportions of distracting trials in each block (20%, 50%, and 80%). The infrequent distractor block (20%) incentivized little distractor suppression, which led to the fastest RT's on distractor absent trials but slowest RT's in the distractor present trials. The frequent distractor block (80%) incentivized more distractor suppression, which led to more similar RT's, but RT's were slightly faster on distractor present trials when compared to distractor absent trials. The block containing maximum uncertainty of a distracting trial (50%) should therefore strike a balance between these two extremes although in their study the attentional capture was still present under those conditions.

The goal of this study is to further examine attentional capture in the visual system, and whether it is modulated by regularities in distractor features irrespective of their spatial location. More importantly, we will examine whether distractor templates can be the cause of this modulation. Earlier physiological studies (Hickey et al., 2009; Gaspar & McDonald, 2014; Lampers et al., 2020) and behavioral studies (Wang & Theeuwes, 2018; Gaspelin & Luck, 2018; Lampers et al., 2020) provide evidence for the existence of a suppressive mechanism operating on feature-based information. Moreover, there is evidence that this suppressive mechanism is reliant on experience concerning first-order feature information of distractors (Gaspelin & Luck, 2018). Due to the fact that feature-based attention can process and modulate information regardless of its location in the visual field (Desimone & Duncan, 1995), statistical learning of distractor feature values could take place regardless of their spatial location and their attentional capture modulated accordingly. Some studies support this notion (Kok, Mostert & De Lange, 2017; Lampers et al., 2020; Chetverikov et al., 2020) describing these functions with templates for rejection. Distractors can therefore become predictable through experience; Experience with distractor feature values will be represented in the distractor template and upcoming distractors fitting the template will be suppressed. But similar results can also be explained by means of habituation, some believing it to be a more parsimonious explanation (Turatto & Pascucci, 2016). A previous study showed that under contexts of maximum distractor uncertainty, attentional capture is minimized as the system strikes a balance between two extreme contextual incentives to suppress distractors (Geyer et al., 2008). Although under those conditions, attentional capture was still observed. All things being equal, attentional capture could therefore be reduced, under the right distractor feature conditions.

We created a covert paradigm similar to the one that Turatto and Pascucci (2016) used in their experiments. Using this paradigm we sought to investigate whether the attentional capture, observed in contexts of maximum distractor uncertainty, could be modulated by means of distractor templates. To test this we used two block types, one block type contained feature regularities in distractors (fixed block) while the other block type did not (random block). Feature regularities in fixed blocks were brought about by making 80% of distractors share the same specific feature value (valid distractors), while the remaining 20% of distractors had their feature values fixed, but in contrast to the other (invalid distractors). In random blocks, the feature values of distractors were always randomly determined. Additionally, we made every participant finish four blocks in total, switching from random and fixed blocks as the experiment went on. Lastly, we ensured preattentive processing of stimuli by presenting the search display for the short duration of 250ms (Albustin, Bacheitner, Djerdjizi & Hollerit, 2010).

Firstly we hypothesize that distractors in our experiment will cause attentional capture. This attentional capture will be reflected in slower RTs on trials when distractors are present compared to trials where they are absent. We further hypothesize that this difference is not due to a more cautious responding style adopted by participants.

Secondly, we hypothesize that attentional capture is modulated by experience with regularities in distractor feature values. This reduced attentional capture will be reflected by reduced mean RT difference between distractor present and distractor absent trials in fixed blocks, compared to the same difference in random blocks.

Thirdly we hypothesize that if attentional capture is modulated by regularities in distractor features. This modulation can be explained with the functions of distractor templates. As we manipulate feature values in fixed blocks, we should see consistent slower RTs in the presence of invalid distractors compared to valid distractors throughout the fixed block condition. This would reflect the probabilistic and accurate functioning of distractor templates in accordance with the bimodal feature distribution of distracting input.

Method

Subjects

Convenience sampling was used to acquire participants for the experiment. Most participants were friends or acquaintances, contacted and invited to participate in the experiment. They were contacted either in person or via message on social media. Some of the participants were researchers at a psychological department, contacted via email with an invitation to take part in this experiment. In total 16 individuals participated in the experiment but due to eye-tracker calibration difficulties and accidental data overwriting, data from two participants were discarded resulting in the overall sample of 14 individuals. Out of those 14 individuals in the sample, 12 were male (87%) and 2 were female (13%) and the mean age of participants was 27 years. All participants were naïve to the purpose of the experiment and received no compensation for their participation of any kind. All participants reported normal or corrected vision, but prior to participation subjects were advised to use contact lenses instead of corrective glasses, if needed, to avoid eye-tracking difficulties.

Apparatus

Participants undertook the experiment inside a sound-attenuated room. The experiment ran on a Windows 10 desktop PC using the software MATLAB (The Math Works, 2020), the software also gathered and stored information on response times and accuracy on each trial. The experiment was displayed on an LCD ASUS 24-inch, 60hz computer monitor, and responses were made via a standard keyboard. An adjustable chin and forehead rest was stationed in front of the monitor and an eye-tracker (an EyeLink 1000 Plus system, SR Research Ltd) was positioned underneath the computer monitor keeping track of eye gaze during the experiment. A laptop computer was connected to the desktop computer running the experiment. A software (a Weblink software, SR Reasearch Ltd) running on the laptop allowed the researcher to both observe real-time eye gaze fixation and to calibrate the eye-tracker before each experimental block.

Stimuli

Throughout the experiment, the background was kept in uniform gray color and during the experimental procedure, all lights in the room were dimmed. Preceding fixed blocks the most probable distractor was presented to subjects. Time intervals and stimuli used within trials are best described using a diagram (see figure 1).

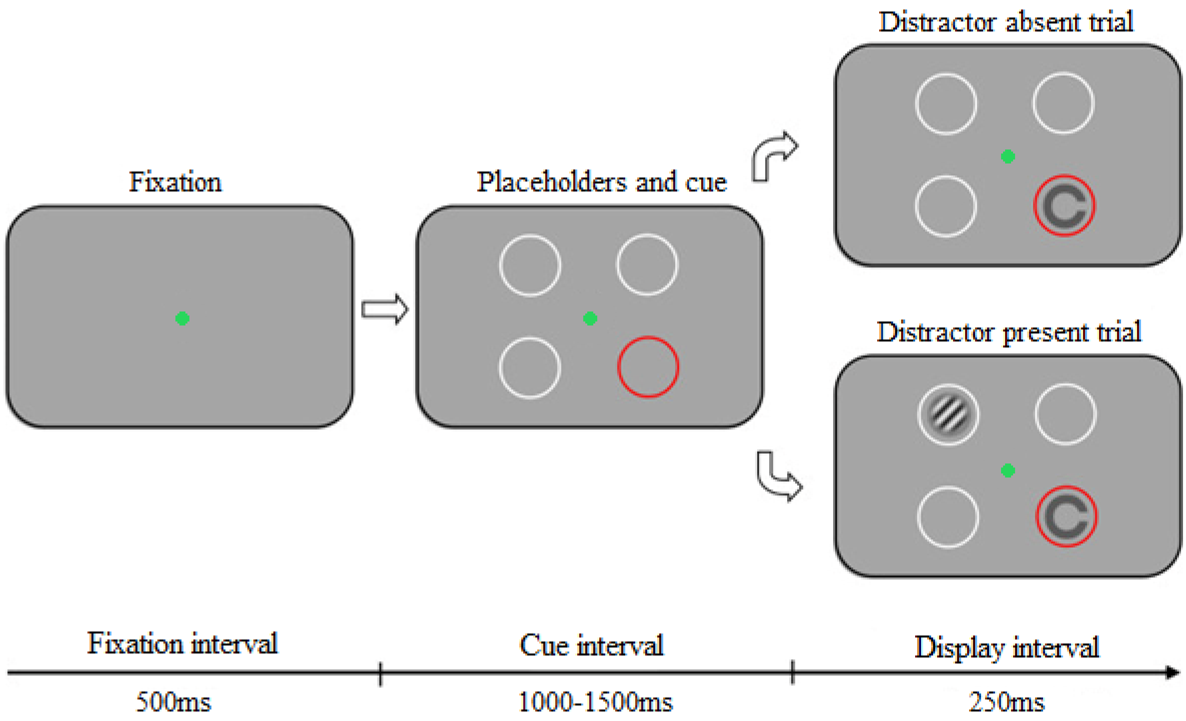

Figure 1. A schematic diagram, illustrating time intervals and stimuli used on trials. Additionally, it shows the distinction between distractor absent and distractor present trials.

A green 0.25° fixation dot was placed at the center of the display. When subjects did not fixate at this dot, a text message appeared instructing subjects to revert their eye gaze back to the fixation point and the trial restarted. The cue interval time randomly varied between trials and could take any of the 6 values ranging from 1000-1500ms in steps of 100ms. Placeholders consisted of four 2° circles with their centers 6° from the center of the screen. A placeholder appearing red represented the cue, which consistently and reliably cued the upcoming target location. The remaining white placeholders signaled a possible upcoming distractor location. The search display, where targets and distractors appeared, was only presented for 250ms and the trial finished when a response had been made. The target we used was a Landholt C, a ring that had a gap either on its right or left side. A single distractor was presented alongside the target on half of the trials throughout the blocks. The distractors we used were 2° Gabor patches with a contrast of 50% Michelson and spatial frequency of 1 cycle per degree. By using Gabor patches we could manipulate feature information in distractors since they can all be defined by their feature category, orientation. Two block types were created, they only differed with respect to the feature values of distractors (see figure 2).

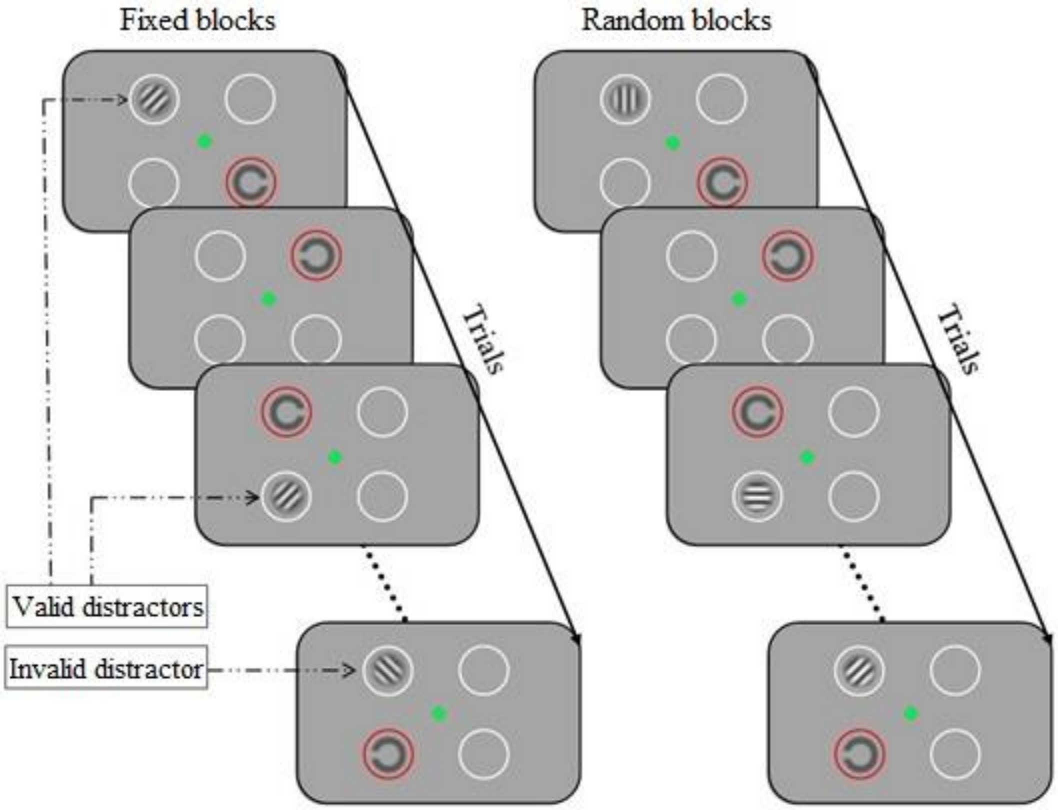

Figure 2. Schematic diagram illustrating hypothetical trial progression within both block types. Feature values of distractors were manipulated in the fixed block type.

Distractors appearing in random blocks had their feature values (orientation) chosen at random from a set of 9 values ranging from 0°-160°, in steps of 20°. More importantly, distractors appearing in fixed blocks had regularities in their feature values. At the start of a fixed block, a single distractor feature value was chosen at random from the same set of values used in random blocks. This exact feature value was then fixed and shared by randomly determined 80% of distractors (valid distractors) appearing in the block. The remaining 20% of distractors (invalid distractors) also had their feature value fixed, but this value was set to be exactly 90° away from the valid distractor orientation.

Design and Procedure

The design of the experiment is a within-subjects design, taking multiple measurements of the same variable under different conditions. The first manipulated factor is distractor presence, it takes two values depending on whether a distractor is present or absent on any given trial. This factor is kept constant at the block level but can vary on a trial-to-trial basis within each block. The second factor is block type, it takes two values, fixed and random. depending on whether feature regularities exist in distractors within a given block. These two factors are our independent variables, creating the conditions of our experiment. We will then measure the effects of these conditions on our dependent variables, reaction times, and correct responses.

Prior to participation, each subject signed an informed consent form. Before starting the experiment, each subject was introduced to the task with a written text appearing on the screen and encouraged to ask if anything was unclear. Subjects then underwent 50 training trials. After finishing their training trials, subjects were allowed to rest before starting blocked trials. Before each block, the eye tracker was calibrated (9-points calibration) and drift correction was performed on a 25 trial interval. Subjects were instructed that the task was to indicate (with arrow keys on a keyboard) as quickly and accurately as possible on which side of the target a gap existed and to try their best to ignore distractors. Each experimental session consisted of 4 blocks, each containing 100 trials. After finishing each block, subjects were encouraged to rest. Each experimental session lasted for about 60 minutes. Counterbalancing was used to prevent order effects. Odd-numbered participants (e.g. First participant, third participant, etc.) started on a fixed block, then moved on to a random block, and then repeated the process. Even-numbered participants (e.g. Second participant, fourth participant, etc.) in contrast, started on a random block, then did a fixed block, and then repeated the process.

Results

Prior to statistical analysis all incorrect responses and outliers in RTs (under 250ms and over 1500ms) were discarded from the dataset (see Table 1). This resulted in the discarding of data from 345 trials (6% of total trials).

Table 1.

Frequency and percentage data concerning incorrect responses and response time outliers.

		Incorrect responses		Outliers in RTs		Trials in condition
Block Type	Distractor	N	%	N	%	N
Random	Present	92	6.5	3	0.2	1400
	Absent	70	5.0	9	0.6	1400
Fixed	Present	90	6.4	2	0.1	1400
	Absent	79	5.6	7	0.5	1400

When all incorrect repsonses and outliers in response times had been discarded from the dataset, the remaining data from participants were graphed and clustered on experimental conditions (see figure 3). Unfortunately, some participants exhibited noisy data, most likely caused by eye tracker issues that some participants reported during the experiment.

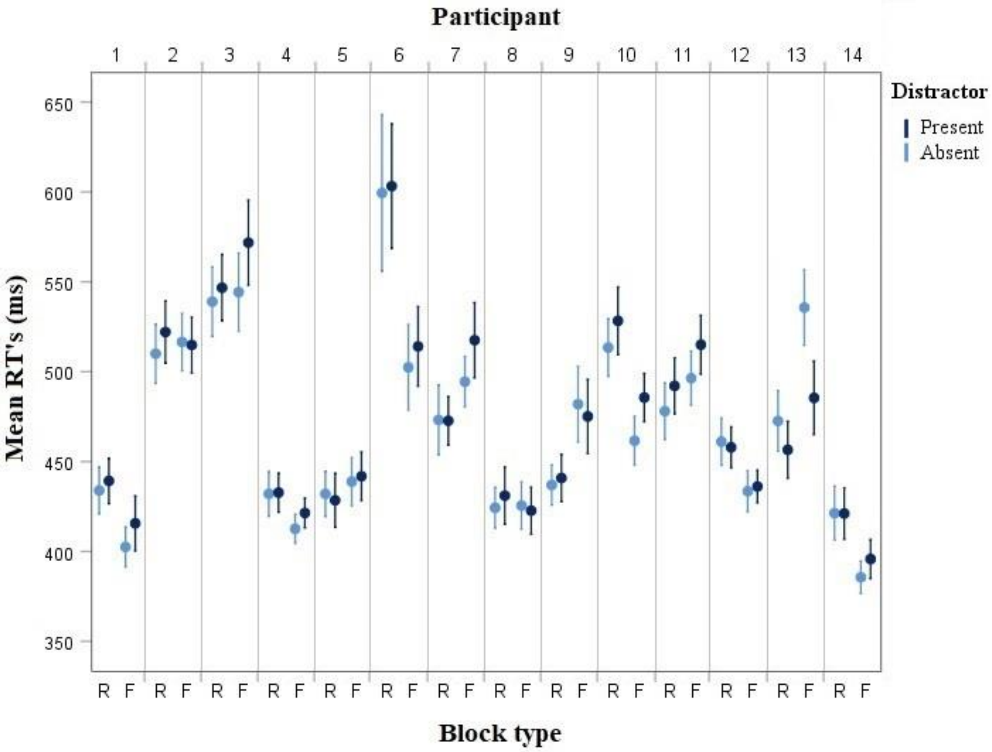

Figure 3. Results from participants reveal noisy data. Some subjects exhibit large differences in mean RTs between block types, most likely caused by eye tracking issues.

Additionally, we graphed and visually observed if changes occurred in the results of the experimental conditions as participants moved from the first to the second half of the experiment (see Figure 4). At first glance, it appears that the paradigm is causing attentional capture as hypothesized and is reflected in slower RTs in presence of distractors in every block. Although this attentional capture does not seem to diminish in fixed blocks as was also hypothesized. Furthermore, the changes appearing between the first and second halves of the experiment are in clear contrast with the hypothesized functions of flexible distractor templates. If these templates are the sole mechanism at work processing and suppressing distractors, we would see no differences appearing between block types in the first and second half of the experiment.

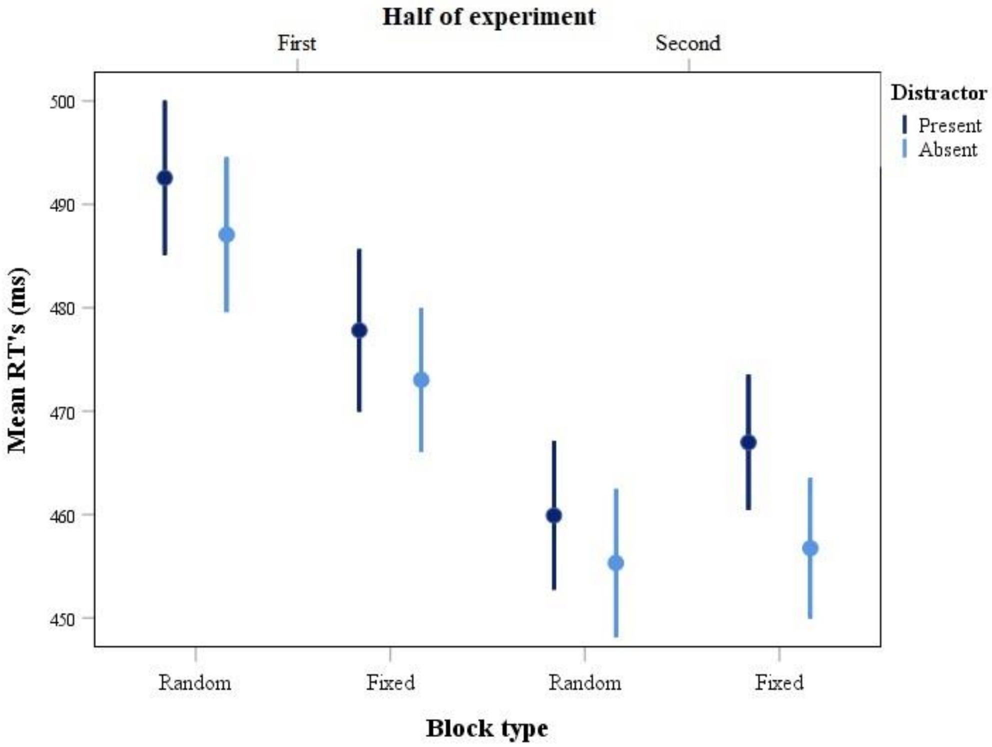

Figure 4. Results of blocks in the first and second half of the experiment reveal an unpredicted trend, fixed blocks seem to hinder performance in the second half of the experiment.

The fundamental aim of the experiment was to investigate whether regularities in feature values of distractors modulate attentional capture. In order to test this, we first need to exhibit that distractors cause attentional capture. To test these hypotheses, we conducted a 2 (distractor present vs distractor absent) x 2 (Fixed block vs random block) repeated-measures ANOVA on RTs.

Due to the prerequisite that attentional capture must be present in our paradigm, we start by reporting the main effects of distractor presence. The main effect of distractor presence on RT's was significant, $F(1,13) = 4.572$, $p = 0.033$, $\eta_p^2 = 0{,}004$. When trials had a distractor present mean RTs were 474ms; In comparison, on trials where distractors were absent, mean RTs were faster or 469ms. This confirms our first hypothesis. Under the conditions of our experiment, attentional capture is observed and reflected in slower mean RTs on trials where distractors are present in comparison to trials where distractors are absent.

We additionally hypothesized that this slowing of RTs in the presence of a distractor could be the result of subjects adopting a more cautious responding style in the presence of a distractor. Since the focus of this experiment is to better understand sensory mechanisms, a more cautious responding style must be disproven to be the cause of these effects. If subjects adopt a more cautious approach when responding in the presence of a distractor they should have more, or at least similar amounts, of correct answers in the presence of a distractor. To test this hypothesis a chi-square test of independence was performed to examine the relation between distractor presence and correct responses. The relation between these variables was significant, X^2 (1, *N* = 5579) = 6.907, *p* = .009. Incorrect responses were more likely in the presence of a distractor than in the absence of one. Leading to the conclusion that the increase in RTs in the presence of a distractor is not the result of a more cautious responding style undertaken by subjects.

The main effects of block type on RT's were also significant *F*(1,13) = 8.590, *p* = 0.003, η_p^2 = 0,007. When blocks had no regularities in distractor feature values the mean RTs were 474ms. In comparison, when blocks had regularities in distractor feature values, mean RTs were faster or 468ms. Although RTs were on average faster in fixed blocks, it does not confirm our second hypothesis concerning reduced attentional capture in fixed blocks. In order to test that hypothesis, we looked at the interaction effects between the two factors.

The results revealed no significant interaction between distractor presence and block type, *F*(1,13) = 0.517, *p* = 0.472, η_p^2 = 0,0001. The effects of distractor presence did thereby not depend on the levels of block type, and vice versa. In other words, we did not observe any modulation of attentional capture by the conditions manipulated at the block level. Regularities in distractor feature values do not modulate attentional capture, at least not under the conditions of our experiment. As a matter of fact, graphical representation of these results shows a slight increase in attentional capture in fixed blocks (see figure 5).

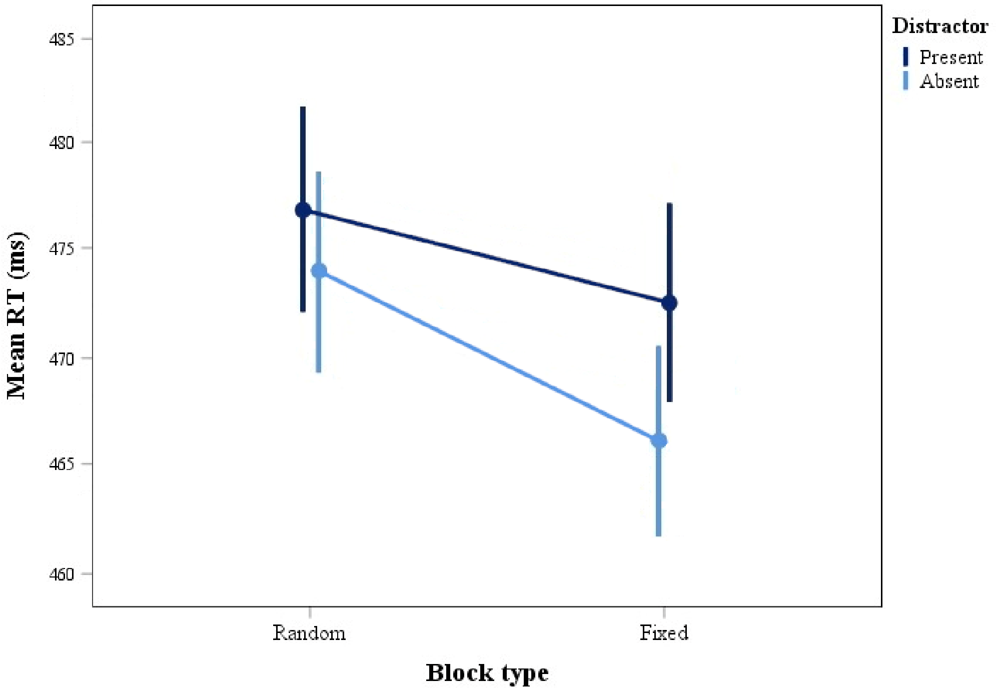

Figure 5. Attentional capture was present in the paradigm. Fixed blocks did not reduce attentional capture caused by distractors, RTs were although generally faster in fixed blocks.

Thirdly we hypothesized that experience with regularities in distractor features would lead to reduced attentional capture through the functions of distractor templates. If such templates operate in a probabilistic manner and accurately represent the bimodal input of distractors in our experiment, we should see consistent differences in RTs between valid and invalid distractor trials throughout the fixed block type. In order to test this hypothesis, we conducted a 2 (valid distractor vs invalid distractor) x 2 (First half vs second half) repeated-measures ANOVA on RTs in fixed block conditions.

The main effects of distractor validity on RTs were non significant $F(1,13) = 3.429$, $p = 0.087$, $\eta_p^2 = 0{,}207$. When trials had an invalid distractor present mean RTs were 481ms; In comparison, when trials had a valid distractor present, mean RTs were faster or 470. Although showing a trend towards the hypothesis and reaching significance, we can not conclude with certainty that the template could differentiate between the two conditions.

The main effects of block half on RTs were also non significant $F(1,13) = 1.017$, $p = 0.332$, $\eta_p^2 = 0{,}072$. In the first half of fixed blocks RTs were 472ms; In comparison, RTs in the second half of blocks was slower, or 480ms.

The results also revealed no significant interaction between distractor validity and block half, $F(1,13) = 0.098$, $p = 0.759$, $\eta_p^2 = 0{,}007$ (see figure 6).

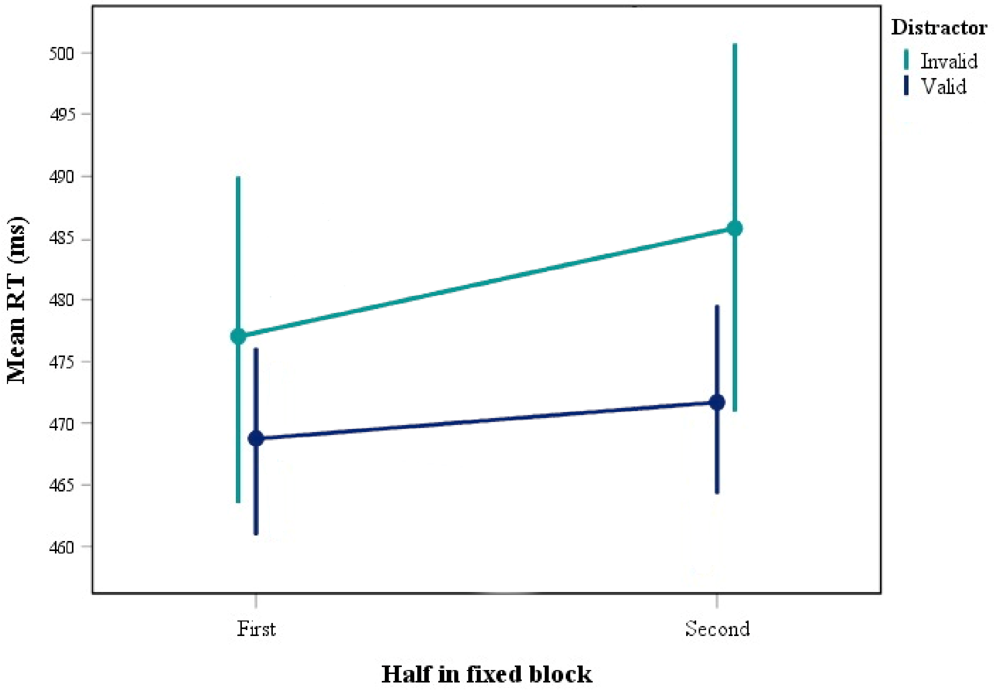

Figure 6. No significant difference was observed between valid and invalid distractor conditions in fixed blocks. Unexpectedly, there was a trend towards slower RTs as subjects progressed through the fixed block condition.

Discussion

We found no support for our hypothesis, that attentional capture could be reduced by regularities in distractor features. We did observe attentional capture in our paradigm, as would be expected based on an earlier study manipulating distractor uncertainty (Geyer et al., 2008). We also confirmed that this attentional capture was not the result of a more cautious responding style adopted by subjects. Earlier notions on the functions of selective attention believed that fully focused attention can not be interrupted by distractors (Theeuwes, 1991), but our results do not support this notion. Since we consistently and reliably cued the target, attention could be focused on the target before distraction. But when distractors were present on trials, RTs were slower. In light of these results, regularities in distractor features could therefore reduce this observed attentional capture. We tested this by looking at the interaction between distractor presence and the block types. The results revealed that attentional capture was not reduced in conditions when distractors had regularities in their features. Although we observed that mean RTs were generally faster in these conditions, it was not only reflected in the distractor present condition, but also in the distractor absent condition. Perhaps reflecting the efficiency by which the distractor suppression mechanism operated (Marini et al., 2013).

Additionally, we hypothesized that if we observed reduced attentional capture in blocks that contained feature regularities, it could be explained by the functions of distractor templates. As postulated by a previous study (Chetverikov et al., 2020) these templates, could in a probabilistic and accurate manner, represent the input of distractors. More importantly, these templates could reflect the bimodal nature of distracting input. As distractors in fixed block conditions could only take two feature values, one more probable than the other, the template should therefore be able to accurately reflect this input and filter distractors accordingly. As valid distractors were more probable, we should therefore observe faster RTs when valid distractors were present, compared to invalid distractors. The data was in line with this notion but statistical analysis revealed a non-significant difference between these conditions, leading to the conclusion that we can not tell for certain whether the template could distinguish between valid and invalid distractor values.

Although purely speculative, there are some indications that habituation could better describe the underlying feature-based suppressive mechanism operating under the condition of our experiment. If habituation to a specific stimulus occurs, any presentations of different stimuli increase the reduced response to the habituated stimulus (Thompson & Spencer, 1966). Since we observed a trend of increased RTs in the presence of both valid and invalid distractors within fixed blocks, there is a strong possibility that habituation is causing both of these feature values to habituate. As subjects progress through trials of the fixed blocks, each presentation of a valid distractor leads to a decrease in the habituated response to an invalid distractor and vice versa. If templates were the underlying mechanism we would not expect these changes to occur, perhaps even a slight decrease in RTs as the template adapts to the task requirements (Chetverikov et al., 2020). Therefore, using this paradigm, one could decipher whether habituation or distractor templates are the underlying distractor suppressive mechanism at work, at least under small set-size conditions, as was the case in our experiment.

It is worth mentioning that some subjects reported issues with eye-tracking. Some of these issues were so pronounced that their experimental session lasted twice as long, compared to subjects that had no issues. Because the mechanisms that we are exploring are highly dependent on temporal factors, these issues might have severely interfered with learning of regularities in distractor features. These issues were most likely caused by drift in the eye tracker software, which can be observed by systematic errors in specific directions. Therefore we recommend that eye tracker data should be examined after collecting data, and screened for these systematic errors, but not used to determine if trials should continue based on online readings.

Inhibition in selective attention shows promise in explaining how not only our goals but also other aspects of the environment shape our ability to focus on task-relevant objects. There is a rapidly growing body of research indicating that inhibition in selective attention is under strong influences of experience and implicit learning mechanisms (vanMoorselaar & Slagter, 2020). But the functions of such mechanisms are hard to decipher since the effects observed in experiments should not be attributed to operations of any single type of mechanism (Kristjánsson & Ásgeirsson, 2019). This attitude, that a single type of mechanism could explain attentional capture reigned supreme in earlier days of research (Katsuki & Constantinidis, 2014). Thankfully, in more recent times, a more cooperative and less dogmatic attitude prevails (Luck, Gaspelin, Folk, Remington & Theeuwes, 2021). Bringing hopes to the subject that someday we might fully understand the intricate workings of visual attention.

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