# Influence of Greater ITI Times on an Object Attention Task: a Behavioral Study

J. A. Konings

# S3637581

j.a.konings@student.rug.nl

Department of Psychology, University of Groningen

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Supervisor: G. R. Mangun

First evaluator: S. Mathôt

Second evaluator: M. Span

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#### Abstract

Selective attention is essential for optimizing cognitive processing by focusing on relevant stimuli and suppressing distractions. This study examines how varying inter-trial interval (ITI) durations affect performance in an object-based attention task. Building on previous work by Noah et al. (2023), we adapted their event-related fMRI paradigm by extending ITI durations to allow for clearer separation of neural responses between trials.

25 participants completed an object attention task, where a category cue (face, scene, or tool) was presented. In valid trials, participants judged whether the cued target (blurred or nonblurred) was present in a pair of overlapping images featuring the cued item and a distractor. In invalid trials, the same cue was presented, but participants judged the blur status of a non-target object paired with a checkerboard pattern.

Results revealed significantly higher accuracy for validly cued trials, p < .001, confirming attentional facilitation. However, response times did not significantly differ between trial types, p = 0.08, suggesting that while accuracy improved with valid cues, response time may not be as sensitive to cue validity under increased ITI conditions. Additionally, a significant cue type interaction was found, p < .001), suggesting that attentional benefits varied across object types. The pos-hoc Turkey test revealed a significant higher response time for cue type face, p < 0.05. These results highlight the importance of timing parameters in attention research, particularly for fMRI studies involving longer trial durations. Future studies should explore the neural underpinnings of object-based attention under varying temporal constraints to enhance our understanding of attentional selection mechanisms.

Keywords: Object-attention, selective attention, Inter-trial-interval

### Influence of Greater ITI Times on an Object Attention Task: a Behavioral Study

The ability to focus on relevant stimuli while avoiding distraction is an important skill to have for daily life. Selective attention is the fundamental cognitive ability that facilitates this ability, and involves the selective processing of task-relevant perceptual information while suppressing distracting signals (James, 1890; van der Heijden, 1992). Studies of the influence of selective attention on sensory and perceptual processing have shown that behavioral performance is enhanced for attended stimuli such that they can be more quickly responded to and more accurately discriminated. (Hawkins et al., 1990; Posner et al., 1980; Purokayastha et al., 2021; Sanders, 1966). This is true for voluntary (goal-driven) attention and for involuntary (stimulus -driven) attention (Jonides, 1981). In this thesis, the focus will be on voluntary visual selective attention, which will hereafter be referred to simply as attention.

# Selective Sensory Processing and Attention

A central question in attention research has been where in sensory information processing it acts, sometimes referred to as the locus of selection. This question was framed in the context of the early versus late selection debate (van der Heijden et al., 1987). That is, does attention act early during sensory processing (Johnston & Dark, 1986), or only later during motor or decision-related processing, either of which could explain improved performance with attention (Duncan, 1980; Norman, 1968). Many psychophysical studies have shown that voluntary attention affects early visual processing, such as contrast sensitivity and spatial resolution, visual properties that are believed to be coded during early sensory processing (Cameron et al., 2002; Carrasco & Barbot, 2019). Other studies have used signal detection methods to demonstrate that attention affects perceptual sensitivity, suggesting early effects of attention (Bashinski & Bacharach, 1980; Cameron et al., 2004; Hawkins et al., 1990).

To more directly test whether attention affects sensory and perceptual processing, many researchers turned to physiological methods that could permit the direct measurement of different stages of visual processing in humans and animals as a function of attention. Work in animals using microelectrode recordings (McAdams & Maunsell, 1999; Moran & Desimone, 1985; Wannig et al., 2011) and humans using signal averaged event-related potentials (ERPs) derived from scalp recordings of the electroencephalogram (EEG) (Mangun & Hillyard, 1991; Rugg et al., 1987; Van Voorhis & Hillyard, 1977; Wijers et al., 1989) have now clearly established that attention can modulate early perceptual processing in sensory-specific cortex as a function of task relevance. Studies using functional brain imaging, such as functional magnetic resonance imaging (fMRI), have also converged to support the view at attention can affect early sensory processing (Corbetta et al., 1990; Heinze et al., 1994; Hopfinger et al., 2000; Kastner et al., 1998; Martinez et al., 1999; Tootell et al., 1998).

As noted earlier, an important goal of selective attention is to help avoid distraction by irrelevant events in the environment. Whether attention works by boosting relevant information (Cameron et al., 2002), supressing irrelevant information (Moran & Desimone, 1985), or both (Couperus & Mangun, 2010; Spitzer et al., 1988; Yoo et al., 2022), has been a key question in attention research (Geng, 2014; van Moorselaar & Slagter, 2020). Most current models of attention include both mechanisms (Couperus & Mangun, 2010; Handel et al., 2008; Moerel et al., 2022), and question are related to where, when and under what conditions attentive processing involves inhibition (Itthipuripat et al., 2017; Wostmann et al., 2022). Taken together, the extant findings lead to the following model framework. Attention facilitates the processing of attended information, while also reducing processing of task-irrelevant visual information, thereby selectively promoting task-relevant information up the visual hierarchy (Bosman et al., 2012; Olshausen et al., 1993). However, interestingly, the majority of the evidence suggests that the unattended task-irrelevant visual information continues to be processed, sometimes to higher levels of the hierarch, even when the suppressed unattended information does not reach perceptual awareness (Luck et al., 1996; Noah et al., 2023; Vogel et al., 2005; Volpe et al.,

1979). Thus, in current models, attention is view as a leaky filter, attenuator or gain-control mechanism – as originally popularized by the work of Anne Treisman (Treisman, 1964) – rather than a strict gating mechanism as sometime described in older models such as Broadbent's selective filter theory (Broadbent, 1958). However, the extent of attenuation clearly varies with factors such as perceptual task and difficulty, and cognitive capacity, such as in Lavie's load theory of attention (Carmel et al., 2011; Lavie, 1995, 2005; Lavie & Tsal, 1994).

### **Voluntary Attention Control**

Theories of voluntary attention include the concept of attentional control, which is embedded in the larger theoretical framework of executive function (Hopfinger & Slotnick, 2020) or cognitive control (Lenartowicz et al., 2010). Attentional control involves the volitional focusing of processing capacity on goal-relevant sensory or cognitive targets (Corbetta & Shulman, 2002). This volitional focusing is also referred as top-down control, in line with the concepts of goal-directed behavior (Gazzaley et al., 2007; Meyyappan et al., 2022; Rashal et al., 2023), and can be contrasted with behaviors that are driven by sensory inputs and generally referred to as bottom-up (Egeth & Yantis, 1997; Jonides, 1981; Jonides & Irwin, 1981; Patel & Sathian, 2000). The conceptual framework is that the changes in visual sensory processing, reviewed in the prior section, results from biasing of sensory structures by top-down control processes (Corbetta & Shulman, 2002; Egeth & Yantis, 1997; Gazzaley et al., 2007; Jonides, 1981; Jonides & Irwin, 1981; Meyyappan et al., 2022; Patel & Sathian, 2000; Rashal et al., 2023). Much work over the past thirty years has focused on understanding the neural mechanisms of top-down attention control.

It is generally believed that voluntary visual attention is controlled by frontal-partietal cortical network of brain structures referred to as the Dorsal Attention Network (DAN) (Armstrong & Moore, 2007; Asplund et al., 2010; Battistoni et al., 2017; Corbetta et al., 2008; Gazzaley & Nobre, 2011; Slagter et al., 2006; Szczepanski et al., 2010; Tamber-Rosenau et al.,

2011; Wager et al., 2004; Woldorff et al., 2004), plus related prefrontal structures, including the inferior frontal junction (IFJ) (Asplund et al., 2010; Baldauf & Desimone, 2014; Bichot et al., 2015; Gong & Liu, 2020; Meyyappan et al., 2021); thalamic structures are also implicated as part of the control circuitry (Saalmann et al., 2012). It is a long-held view that the DAN issues control signals (Corbetta & Shulman, 2002; Rajan et al., 2021), transmitted via top-down neural pathways, to modulate activity in visual cortex. This modulation leads to biasing of sensory processing based on stimulus relevance, and ultimately results in stimulus selection (Buschman & Kastner, 2015; Desimone & Duncan, 1995; Mangun & Hillyard, 1991; Moran & Desimone, 1985). In covert cue-target attention paradigms, such as that used in this thesis (Mangun & Hillyard, 1991; Poletti et al., 2017; Posner, 1980), top-down control processes and their biasing of sensory structures occur during the anticipatory period following an attention-directing cue and before arrival of the target stimuli, and the effects of this top-down control are observed as selective processing of the subsequent targets (Corbetta & Shulman, 2002; Hopfinger et al., 2000; Martinez et al., 1999; Woldorff et al., 2004).

During the anticipatory period following an attention-directing cue, two changes in visual cortex have been observed. One is that baseline neural activity increases in regions of visual cortex corresponding to the attended location. Such baseline increases in neural activity have been observed in monkey single unit studies (Luck et al., 1997), in human EEG (Clements et al., 2023; Worden et al., 2000) and ERP studies (Hopf & Mangun, 2000), as well as in fMRI studies (Chawla et al., 1999; Hopfinger et al., 2000; Kastner et al., 1999). The other involves changes in EEG oscillatory activity, especially in the alpha band.

# **EEG Alpha as an Attention Mechanism**

Alpha band oscillations (8-12 Hz) are the dominant rhythm in both the resting and active brain (Ippolito et al., 2022). When there is a significant change in the amplitude of alpha oscillations following an external or internal event, it's termed as event-related synchronization

(ERS) when alpha power increases, and event-related desynchronization (ERD) when alpha power drops (Pfurtscheller & Lopes da Silva, 1999). Synchronization indicates an increase in the rhythmic activity of large populations of neurons. Alpha synchronization (increased alpha power) appears to play a role in maintaining an active and adaptive inhibitory mechanism for the suppression of irrelevant information (Klimesch, 2012). The state of cortex as indexed by alpha has also been shown to predict perceptual sensitivity such that when alpha power is high, perceptual sensitivity is low (Di Gregorio et al., 2022; Romei et al., 2008). That is, alpha power is inversely related to the degree of cortical local inhibition, as described in the Gating by Inhibition model of Jensen and Mazaheri (Jensen & Mazaheri, 2010).

The Gating of Inhibition model of EEG alpha has been used to explain findings in studies of attention, and to suggest mechanisms for attention selection. A role for alpha was first reported in studies of selection attention in trial-by-trial cuing paradigms manipulating spatial attention. It was found that when covert attention is directed to one visual hemifield (e.g. right visual field), then alpha decreases over the contralateral (left) occipital scalp, but increases over the ipsilateral (right) occipital scalp (Worden et al., 2000). Thus, the idea was that the cortex representing the attended hemifield location showed alpha desynchronization (reduced alpha power) while the opposite visual cortex, representing the unattended visual field displayed alpha synchronization (increased alpha power). Thus, increased alpha power was a mechanism to inhibit processing in the cortical zone that would receive the unattended (to-be-ignored) stimulus.

How general is the gating of inhibition model? For example, can it explain attention selection in non-spatial attention? This question was investigated by Synder and Foxe (Snyder & Foxe, 2010). They found the same inhibitory effect of alpha during an attention task to stimulus features color versus motion. When attention was cued to the color of an upcoming target stimulus, increased alpha power was observed over the visual cortex specialized for

motion processing (human area MT/V5), and vice versa for attention to motion while ignoring color. In more recent work researchers investigated whether this role of alpha changes in selective attention might also operate at even higher levels of the perceptual system, during selective attention to objects (Noah et al., 2020). Noah and colleagues examined whether attention directed towards objects (face, scenes or tools) elicited comparable changes in focal cortical excitability mediated by alpha activity. They used multivariate decoding of alpha power (attend-face; attend-scene; attend-tool) and found that differing patterns of scalp-recorder alpha distinguished the different attention conditions in this high-level object attention task.

One drawback of scalp-recorded EEG measures and EEG decoding is that this approach does not provide the exact location of the increasing and decreasing alpha activity in the brain. Scalp-recorded EEG is a brain recording method, but not a 3-D neuroimaging tool (Luck, 2014). In contrast, neuroimaging methods such as fMRI can provide high-resolution measures of where in the brain activity increases and decrease with attention. It would be important to know whether the differences found in the Noah et al. study for alpha activity represented changed in local cortical activity in regions specialized for processing faces, scenes and tools, in order to conclude that the decoding findings represent an implementation of alpha suppression in line with the Grating by Inhibition Model.

### Task Timing Parameters and Behavioral Measures of Object Attention

This thesis represents a key first step toward the goal of replicating the Noah et al. (2020) study in the fMRI scanner. It provides a behavioral replication and extension of the Noah et al. study (their Experiment 3) using task parameters that adapt the study for event-related fMRI methods. The stimulus onset asynchrony (SOA) and intertrial interval (ITI) times of the original EEG study were too short (1000-2500 milliseconds and 1500-2500 milliseconds) for an event-related fMRI study, owing to the fact that the fMRI Blood Oxygenation Level Depend (BOLD) signal – a measure tracking blood hemodynamics that is a proxy for local neural activity – is a

sluggish response, taking seconds (not milliseconds) to begin, peak and return to baseline (liao et al., 2002). Thus, if the stimuli in the task are too close together, the overlapping BOLD signals (e.g. related to cues and targets) cannot be distinguished from one another (Burock et al., 1998; Das et al., 2023). Therefore, the SOA and ITI durations need to be adjusted to be appropriate for fMRI; for example, in the range of 2000-8000 milliseconds (Das et al., 2023; Grent-'t-Jong & Woldorff, 2007; Miezin et al., 2000; Woldorff et al., 2004).

Before the study can be conducted using fMRI, it is critical to know if the adjusted (longer) SOA and ITI times will fundamentally alter the nature of the object attention task. In this thesis, I investigate the behavioral effects of the adjusted SOA and ITI time on the experiment of Noah et al. (2023). I hypothesize that the adjusted SOA and ITI time will not alter with the results of Noah et al. (2023). Therefore, I hypothesize that cueing subjects to selectively attend to specific objects in an upcoming stimulus will result in enhanced performance for the cued relative to uncued object targets.

#### Methods

### <u>Participants</u>

A total of 32 undergraduate students from the University of California, Davis participated in the study. All participants reported normal or corrected-to-normal vision and no history of neuropsychiatric disorders. Written informed consent was obtained prior to participation. Compensation was provided in the form of course credit through the university's SONA research participation system. Data from seven participants were excluded from analysis based on predefined criteria, which included task accuracy below 60%, failure to maintain gaze on the central fixation point, or observable signs of disengagement (e.g., drowsiness). Additionally, some participants voluntarily withdrew. The final sample included 25 individuals. This sample size was determined based on effect sizes observed in previous decoding studies (Noah et al., 2020; 2023).

# <u>Apparatus and Stimuli</u>

Participants were seated comfortably in a sound-attenuated and electromagnetically shielded room (ETS-Lindgren) designed to minimize external interference. Visual stimuli were displayed on a VIEWPixx/EEG LED monitor (model VPX-2006A; VPixx Technologies Inc.), positioned at eye level and viewed from a distance of 80 cm. The monitor measured 60 cm diagonally, featured a resolution of  $1920 \times 1080$  pixels, and refreshed at 120 Hz. To reduce glare and reflected light, the room interior and equipment were painted black, with soft ambient illumination provided by DC lighting.

Stimuli consisted of composite images created by overlaying two object images—one from a cued target category and another from a non-cued distractor category (see Figure 1). On each trial, participants viewed these briefly presented composites and judged whether the image from the cued type (face, scene, or tool) was clear or blurred. Both the target and distractor images could independently appear in clear or blurred form, requiring participants to rely on the cue type rather than simply detecting the presence of blur. Thus, successful performance depended on object-based attentional selection guided by the cue.

# Figure 1

# Example Valid and Invalid Trial Stimuli



Each trial began with the brief presentation (200 ms) of one of three symbolic cues-a triangle, square, or circle—each measuring  $1^{\circ} \times 1^{\circ}$  of visual angle. These cues were selected in a pseudorandom order and displayed 1° above the central fixation point, using PsychoToolbox (Brainard, 1997). Each cue indicated, with 80% validity, which object category (face, scene, or tool) was likely to appear in the upcoming stimulus, directing participants' attention toward that category.

Following the cue, a stimulus onset asynchrony (SOA) was randomly selected from a range of 2000 to 8000 milliseconds. After this interval, a composite target image  $(5^{\circ} \times 5^{\circ})$ appeared at fixation for 100 milliseconds. Each composite included a cued-category target (if valid) and a distractor image. Trials were separated by a variable intertrial interval (ITI), also ranging from 2000 to 8000 milliseconds, measured from the offset of the target to the onset of the next cue (see Figure 2).

### Figure 2

**Example Invalid Trial Stimuli** 





To evaluate the influence of cue validity on performance, 20% of trials were deliberately invalid. In these trials, the stimulus featured an image from a randomly selected non-cued object category, overlaid with a black-and-white checkerboard pattern. The checkerboard, which varied independently in clarity (blurred or in focus), was never task-relevant. Participants were instructed that when a stimulus did not include an image from the cued category, they should instead evaluate whether the visible non-cued object was blurry or not, disregarding the checkerboard.

All stimulus images were displayed within a  $5^{\circ} \times 5^{\circ}$  square of visual angle. Blurred versions of images were created by applying a Gaussian filter (standard deviation = 2) using the *imgaussfilt()* function in MATLAB. All stimuli were presented against a neutral gray background (RGB: 128, 128, 128), with a white fixation dot at the center of the display.

Each of the three object categories (faces, scenes, tools) included 40 unique images. Composite stimuli were created by randomly combining images from these categories on a trial-by-trial basis. Face images—featuring front-facing, neutral expressions—were sourced from a standardized dataset (Ma et al., 2015), cropped into ovals, and set against white backgrounds. Scene images were drawn from two natural image sets (Geisler & Perry, 2011; Burge & Geisler, 2011) and covered the full display area. Tool images were obtained from the Bank of Standardized Stimuli (Brodeur et al., 2014), also cropped and presented on white backgrounds.

To prevent participants from relying on spatial cues rather than object-based attention, the position of face and tool images (which lacked full-frame visual detail) was randomly displaced from the center of the display. This ensured that attention had to be directed based on object identity and not spatial location when performing the clarity discrimination task.

#### **Procedure**

Participants were instructed to maintain steady fixation at the center of the screen throughout each trial and to prepare for the appearance of the cued object category. Upon presentation of the target image, they were to respond as quickly as possible by indicating whether the image appeared blurry or not. Responses were made via keyboard: the 's' key for blurry and the 'd' key for not blurry. Only responses made within a 2.5-second window following target onset were recorded.

To emphasize the importance of preparatory attention, participants were told to anticipate the cued object type during the delay period before target onset. All participants completed a training session consisting of at least 24 practice trials and were required to reach a minimum accuracy threshold of 60%. During this phase, the duration of stimulus presentation was adjusted individually to ensure task comprehension. Following training, each participant completed 10 blocks (including practice), with each block consisting of 24 trials, resulting in a total of 240 trials per participant.

#### Results

In the current study the effects of the adjusted SOA and ITI times on an object attention task was investigated. First, we expected that the changes in stimulus-presentation times would not alter the pattern of results as reported by Noah et al. (2023). Therefore, we expected that participants would exhibit higher response times on invalidly cued trials, and lower response times on valid cued trials. The data was processed using MATLAB. The logfiles per subject were loaded and the first block of every participant was deleted, this was due to it being a practice block to get familiar with the task. The data was then filtered on an accuracy of 60% or higher per block. To examine the impact of altered ITI times on task performance, two separate two-way ANOVAs were conducted. The first assessed the effects of cue type and validity on accuracy, while the second examined these effects on response time.

### <u>Accuracy</u>

A two-way ANOVA with cue type and validity as independent variables and accuracy as dependent variable revealed that the main effect of cue type was not statistically significant, F(2, 62) = 0.13, p = .880,  $\eta^2 = .002$ , indicating that there were no significant differences in accuracy between the three cue types. In contrast, the main effect of validity was significant, F(1, 62) = 46.08, p < .001,  $\eta^2 = .422$ , suggesting that accuracy was significantly higher for valid trials compared to invalid trials. The interaction between cue type and validity was also not significant, F(2, 62) = 0.42, p = .662,  $\eta^2 = .008$ , indicating that the effect of validity on accuracy did not differ across cue types.

To illustrate these results, accuracy per cue type for valid trials is highest for face (M = 0.90; SD = 0.15), followed by tool (M = 0.90; SD = 0.14), and last for scene (M = 0.84; SD = 0.17). For invalid trials, accuracy is the highest for scene (M = 0.61; SD = 0.39), next for tool (M = 0.57; SD = 0.39), and last for face (M = 0.55; SD = 0.36).

Assumption check. The assumptions for a two-way ANOVA were assessed prior to analysis. Visual inspection of histograms and Q-Q plots indicated that the residuals were approximately normally distributed for each group. Levene's test for homogeneity of variances revealed a significant result (F(5, 62) = 4.91, p < 0.001), suggesting a violation of the assumption of equal variances. Despite this violation, a standard two-way ANOVA was conducted. It is important to note that this assumption violation may affect the validity of the results. No extreme outliers were detected based on boxplots.

# Figure 3





Note. The error-bars were based on a 95% within subjects interval.

### **Response Time**

A two-way ANOVA revealed a significant main effect of cue type (F(2, 2666) = 7.37, p < .001), indicating that response times differed significantly between the three cue types. There was no significant main effect of validity (F(1, 2666) = 3.06, p = .081), and no significant interaction between cue type and validity (F(2, 2666) = 0.48, p = .621), shown in figure 4. To illustrate these results, response time for valid trials per cue type was the lowest for face (M = 1.12; SD = 0.39), then for tool (M = 1.21; SD = 0.39), and higest for scene (M = 1.12; SD = 0.39). The response time for invalid trial per cue type was the lowest for face (M = 1.12; SD = 0.42), then for tool (M = 1.17; SD = 0.42), and highest for scene (M = 1.19; SD = 0.43).

A post-hoc Tukey test showed that participants responded significantly faster to face cues compared to both scene cues (Mdiff = -0.081, 95% CI [-0.132, -0.030], p < .001) and tool cues (Mdiff = -0.060, 95% CI [-0.112, -0.009], p = .017). There was no significant difference in response times between scene and tool cues (Mdiff = 0.021, 95% CI [-0.031, 0.073], p = .611).

Assumptions check. Prior to conducting the two-way ANOVA, the assumptions were evaluated. Visual inspection of histograms and Q-Q plots suggested that the residuals were approximately normally distributed for each group. Levene's test indicated that the assumption of homogeneity of variances was met, p > .05. Additionally, no extreme outliers were detected in the response time data based on boxplots. Therefore, the assumptions for conducting a two-way ANOVA were considered adequately satisfied.

**Figure 4** *Graph Effect of Trial Validity on RT by Cue type* 



Note. The error-bars were based on a 95% within subjects interval. RT = Response Time

Comparison with Noah et al. (2023)

The present study aimed to investigate the effects of increased inter-trial interval (ITI) times on an object-based attention task, building upon the findings of Noah et al. (2023). Their study demonstrated that object-based selective attention enhances accuracy on validly cued trials and results in a response time cost on invalidly cued trials. These findings support classical attentional facilitation theories, which argue that attention enhances processing of spatially or contextually relevant stimuli, thereby improving accuracy and efficiency.

Consistent with Noah et al. (2023), our results showed a clear attentional benefit for validly cued trials, as reflected in significantly higher accuracy compared to invalidly cued trials. This suggests that even with altered ITI and SOA parameters, participants still exhibited a reliable object-based attention effect in terms of accuracy. However, our findings diverged slightly with respect to response times. While Noah et al. (2023) reported significantly longer response times for invalid trials, indicative of a cost associated with attentional reorienting, we found no significant effect of validity on response time, and no interaction between cue type and validity. This might suggest that the increased ITI reduced the urgency or cognitive load of attentional reallocation, thereby diminishing the expected response time cost for invalid trials.

Overall, the core attentional facilitation effect observed by Noah et al. (2023) was replicated in terms of accuracy. However, the modified temporal parameters may have influenced the dynamics of attentional disengagement and reorienting, as reflected in the absence of a significant validity effect in response times.

#### Discussion

This study investigated the impact of extended inter-trial interval (ITI) and stimulus onset asynchrony (SOA) times on object-based attentional performance, adapting the paradigm of Noah et al. (2023) for use in event-related fMRI. Our findings confirmed that attentional cues significantly improved accuracy for validly cued trials compared to invalid ones, replicating core findings from previous research. However, contrary to expectations and prior reports, we did not observe a significant effect of cue validity on response times. This suggests that while the attentional benefit on accuracy was preserved, temporal adjustments to the task may have altered the underlying dynamics of attentional allocation and disengagement.

# The Role of ITI and SOA in Object-Based Attention

One of the primary objectives of this study was to determine whether the prolonged ITI and SOA times, adapted for event-related fMRI paradigms, would affect behavioral performance. Our findings suggest that while the fundamental mechanisms of object-based attention remain intact, the increased temporal separation between trials may have reduced attentional carryover effects, leading to the absence of a response time difference between valid and invalid trials. This is consistent with previous research showing that shorter ITIs can create lingering attentional biases, which increase reaction time costs for invalidly cued stimuli (Mangun & Hillyard, 1991; Woldorff et al., 2004).

Our results suggest that the temporal parameters of attention tasks play a critical role in modulating attentional effects. Specifically, the longer ITI and SOA may have allowed participants sufficient time to reset their attentional state between trials, thereby minimizing interference from previous cues. This could explain why we did not observe the expected response time differences. Future research should explore the precise timing mechanisms underlying attentional disengagement and whether there is an optimal ITI range for studying object-based attention in behavioral and neuroimaging contexts.

### **Cue-type Effects and Object-Based Attentional Mechanisms**

Previous research has debated whether or not attentional benefits vary across different object categories. Some have found that faces often showed stronger attentional effects compared to other stimuli (Quek & Heering, 2024). However, the research of Noah et al. (2020; 2023) did not find a difference between the object categories for the valid and invalid trials. My study did reveal a significant difference in accuracy for valid and invalid trials, with a higher accuracy for valid trials, but it showed no difference between the cue types. However, this current study did reveal a difference in response time between object categories for the total of trials and for the valid trials, with a fastest response time for cue type face. This may indicate that with longer ITI times, attentional benefits are distributed unevenly across stimulus types, potentially increasing object-specific attentional biases. Alternatively, the influence of a cue type interaction may reflect differences in stimulus processing demands or task difficulty across studies.

Another possible explanation is that our task design, which required participants to determine whether the target image was blurred or not, may have engaged more general visual discrimination mechanisms rather than object-specific attentional processes. Future studies should investigate whether different task demands (e.g., object identification vs. perceptual discrimination) influence the extent of cue type interactions in object-based attention.

### **Theoretical frameworks**

The results align with established theories of attentional facilitation, such as the biased competition model (Desimone & Duncan, 1995), which posits that attention enhances processing of relevant stimuli while suppressing irrelevant information. The significant accuracy advantage in validly cued trials suggests that the attentional cues enhanced attention to allocate cognitive resources to the relevant object category, leading to improved perceptual discrimination, which is in contrast to Noah et al. (2023).

However, the absence of a significant response time cost for invalid trials challenges traditional models that predict attentional disengagement delays when attention is misdirected (Posner, 1980). One possible explanation is that longer ITIs allowed participants to fully reset their attentional state before the next trial minimizing lingering effect from the previous cue. This interpretation aligns with findings on attentional recovery dynamics (Grent-'t-Jong & Woldorff, 2007), which suggest that attentional effects diminish over time, particularly when there ITIs are long enough to allow complete disengagement from previous trials.

However, could long ITI times also cause a lack of focus, leading participants to disengage not only from prior cues but also from the task itself? Extended ITIs may introduce periods of inattention or mind-wandering, reducing overall task engagement and weakening the impact of attentional cues. If participants become less engaged due to prolonged gaps between trials, the expected response time cost for invalid trials may be diminished, not because of improved attentional resetting, but due to a general decrease in sustained attention. Future studies should investigate whether excessively long ITIs impair task performance by reducing attentional readiness, possibly through behavioral measures of sustained attention or neurophysiological markers such as EEG alpha activity.

# **Implications for Future Research**

My findings provide important insights into the role of temporal parameters in objectbased attention tasks. The results suggest that while increased ITI times do not fundamentally alter attentional facilitation effects, they may influence response time costs and categoryspecific attentional biases. This has implications for designing future experiments, particularly those using event-related fMRI, where careful consideration of timing parameters is essential to isolate attentional effects from overlapping neural responses.

Future studies should further examine the neural mechanisms underlying these behavioral effects using neuroimaging techniques, such as fMRI or EEG, to determine whether longer ITI times alter the neural correlates of object-based attention. Additionally, investigating the interaction between attentional selection and working memory processes could provide further insights into how attention is sustained and reallocated across trials.

#### **Conclusion**

The current study provides important insights into how inter-trial interval durations affect object-based selective attention. While we replicated the accuracy benefits of valid cues, the absence of a significant response time cost for invalid cues suggests that longer ITIs may facilitate attentional disengagement, reducing response delays. These findings have implications for attention theories, particularly in understanding the temporal dynamics of attentional reset. Future research should explore the underlying neural mechanisms using neuroimaging techniques and extend these findings to other sensory modalities and populations. By refining our understanding of how temporal parameters shape attentional processing, we can advance both theoretical models and practical applications in cognitive neuroscience and clinical interventions.

## Reference

- Armstrong, K. M., & Moore, T. (2007). Rapid enhancement of visual cortical response discriminability by microstimulation of the frontal eye field. *Proc Natl Acad Sci U S A*, 104(22), 9499-9504. <u>https://doi.org/0701104104</u>
- Asplund, C. L., Todd, J. J., Snyder, A. P., & Marois, R. (2010). A central role for the lateral prefrontal cortex in goal-directed and stimulus-driven attention. *Nat Neurosci*, 13(4), 507-512. <u>https://doi.org/nn.2509</u>
- Baldauf, D., & Desimone, R. (2014). Neural mechanisms of object-based attention. *Science*, 344(6182), 424-427. <u>https://doi.org/10.1126/science.1247003</u>
- Bae, G. Y., & Luck, S. J. (2018). Dissociable decoding of spatial attention and working memory from EEG oscillations and sustained potentials. *The Journal of Neuroscience*, 38(2), 409–422. https://doi-org.proxy-ub.rug.nl/10.1523/JNEUROSCI. 2860-17.2017
- Bashinski, H. S., & Bacharach, V. R. (1980). Enhancement of perceptual sensitivity as the result of selectively attending to spatial locations. *Percept Psychophys*, 28(3), 241-248. https://doi.org/10.3758/bf03204380
- Battistoni, E., Stein, T., & Peelen, M. V. (2017). Preparatory attention in visual cortex. *Ann N Y Acad Sci.* <u>https://doi.org/10.1111/nyas.13320</u>
- Bichot, N. P., Heard, M. T., DeGennaro, E. M., & Desimone, R. (2015). A Source for Feature-Based Attention in the Prefrontal Cortex. *Neuron*, 88(4), 832-844.
- Bosman, C. A., Schoffelen, J. M., Brunet, N., Oostenveld, R., Bastos, A. M., Womelsdorf, T., et al. (2012). Attentional stimulus selection through selective synchronization between monkey visual areas. Neuron, 75, 875–888. https://doi.org/10.1016/j.neuron.2012.06.
  037

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*, 433–436. https://doi.or g/10.1163/156856897x00357

Broadbent, D. E. (1958). Perception and communication. Pergamon Press.

- Brodeur, M. B., Guérard, K., & Bouras, M. (2014). Bank of Standardized Stimuli (BOSS) phase II: 930 new normative photos. PLoS One, 9, e106953. https://doi.org/10.1371/j ournal.pone.0106953
- Burge, J., & Geisler, W. S. (2011). Optimal defocus estimation in individual natural images. *Proceedings of the National Academy of Sciences*, U.S.A., 108, 16849–16854.
- Burock, M. A., Buckner, R. L., Woldorff, M. G., Rosen, B. R., & Dale, A. M. (1998). Randomized event-related experimental designs allow for extremely rapid presentation rates using functional MRI. *Neuroreport*, 9(16), 3735-3739.
- Buschman, T. J., & Kastner, S. (2015). From Behavior to Neural Dynamics: An Integrated Theory of Attention. *Neuron*, *88*(1), 127-144.
- Cameron, E. L., Tai, J. C., & Carrasco, M. (2002). Covert attention affects the psychometric function of contrast sensitivity. *Vision Research*, 42(8), 949–967. https://doi-org.proxyub.rug.nl/10.1016/S0042-6989(02)00039-1
- Cameron, E. L., Tai, J. C., Eckstein, M. P., & Carrasco, M. (2004). Signal detection theory applied to three visual search tasks--identification, yes/no detection and localization. *Spat Vis*, *17*(4-5), 295-325.
- Carmel, D., Thorne, J. D., Rees, G., & Lavie, N. (2011). Perceptual load alters visual excitability. *J Exp Psychol Hum Percept Perform*, *37*(5), 1350-1360.
- Carrasco, M., & Barbot, A. (2019). Spatial attention alters visual appearance. *Current opinion in psychology*, *29*, 56–64.
- Chawla, D., Rees, G., & Friston, K. J. (1999). The physiological basis of attentional modulation in extrastriate visual areas. *Nat Neurosci*, *2*(7), 671-676.

- Clements, G. M., Gyurkovics, M., Low, K. A., Kramer, A. F., Beck, D. M., Fabiani, M., & Gratton, G. (2023). Dynamics of alpha suppression index both modality specific and general attention processes. *Neuroimage*, 119956.
- Corbetta, M., Miezin, F. M., Dobmeyer, S., Shulman, G. L., & Petersen, S. E. (1990).
   Attentional modulation of neural processing of shape, color, and velocity in humans.
   Science, 248(4962), 1556-1559. <u>http://www.ncbi.nlm.nih.gov/pubmed/2360050</u>
- Corbetta, M. & Shulman, G. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, *3*, 201–215. https://doi.org/10.1038/nrn755
- Corbetta, M., Patel, G., & Shulman, G. L. (2008). The reorienting system of the human brain: from environment to theory of mind. *Neuron*, *58*(3), 306-324. <u>https://doi.org/S0896-6273(08)00369-3</u>
- Couperus, J. W., & Mangun, G. R. (2010). Signal enhancement and suppression during visual-spatial selective attention. *Brain Res*, *1359*, 155-177.
- Das, S., Ding, M., Yi, W., & Mangun, G. R. (2023). Optimizing cognitive neuroscience experiments for separating event- related fMRI BOLD responses in non-randomized alternating designs. *Frontiers in Neuroimaging*, 2.
- Desimone, R., & Duncan, J. (1995). Neural Mechanisms of Selective Visual-Attention. Annual Review of Neuroscience, 18, 193-222.
- Di Gregorio, F., Trajkovic, J., Roperti, C., Marcantoni, E., Di Luzio, P., Avenanti, A., Thut, G.,
  & Romei, V. (2022). Tuning alpha rhythms to shape conscious visual perception. *Curr Biol*, *32*(5), 988-998 e986.
- Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. *Psychol Rev*, 87(3), 272-300. https://www.ncbi.nlm.nih.gov/pubmed/7384344
- Egeth, H. E., & Yantis, S. (1997). Visual attention: control, representation, and time course. Annu Rev Psychol, 48, 269-297. <u>https://doi.org/10.1146/annurev.psych.48.1.269</u>

- Gazzaley, A., & Nobre, A. C. (2011). Top-down modulation: bridging selective attention and working memory. *Trends Cogn Sci.* <u>https://doi.org/S1364-6613(11)00247-6</u>
- Gazzaley, A., Rissman, J., Cooney, J., Rutman, A., Seibert, T., Clapp, W., & D'Esposito, M. (2007). Functional interactions between prefrontal and visual association cortex contribute to top-down modulation of visual processing. *Cereb Cortex*, 17 Suppl 1, i125-135.
- Gazzaniga, M. S., Ivry, R. B. & Mangun, G. R. (2019). Attention. In *Cognitive Neuroscience: the Biology of the Mind* (5th ed., 274-323). W. W. Norton & Company.
- Geisler, W. S., & Perry, J. S. (2011). Statistics for optimal point prediction in natural images. Journal of Vision, 11, 14. https://doi.org/10.1167/11.12.14
- Geng, J. J. (2014). Attentional Mechanisms of Distractor Suppression. *Current Directions in Psychological Science*, 23(2), 147-153. https://doi.org/10.1177/0963721414525780
- Gong, M., & Liu, T. (2020). Biased Neural Representation of Feature-Based Attention in the Human Frontoparietal Network. *J Neurosci*, 40(43), 8386-8395.
- Grent-'t-Jong, T., & Woldorff, M. G. (2007). Timing and sequence of brain activity in topdown control of visual-spatial attention. *PLoS biology*, 5(1), e12. https://doi.org/10 .1371/journal.pbio.0050012
- Händel, B., Lutzenberger, W., Thier, P. & Haarmeier, T. (2008). Selective Attention Increases the Dependency of Cortical Responses on Visual Motion Coherence in Man. *Cerebral Cortex*, 18(12), 2902–2908, https://doi.org/10.1093/cercor/bhn049
- Handy, T. C., & Mangun, G. R. (2000). Attention and spatial selection: Electrophysiological evidence for modulation by perceptual load. *Perception & Psychophysics*, 62(1), 175–186. https://doi-org.proxy-ub.rug.nl/10.3758/BF03212070

- Hawkins, H. L., Hillyard, S. A., Luck, S. J., Mouloua, M., Downing, C. J., & Woodward, D. P. (1990). Visual attention modulates signal detectability. *Journal of experimental psychology. Human perception and performance*, *16*(4), 802–811.
- He, B. J. & Raichle, M. E. (2009). The fMRI signal, slow cortical potential and consciousness. *Trends in Cognitive Sciences*, *13*(7), 302-309.
- Heinze, H. J., Mangun, G. R., Burchert, W., Hinrichs, H., Scholz, M., Munte, T. F., Gos, A., Scherg, M., Johannes, S., Hundeshagen, H., & et al. (1994). Combined spatial and temporal imaging of brain activity during visual selective attention in humans. *Nature*, *372*(6506), 543-546. <u>https://doi.org/10.1038/372543a0</u>
- Hillyard, S. A., Vogel, E. K. & Luck, S. J. (1998). Sensory gain control (amplification) as a mechanism of selective attention: electrophysiological and neuroimaging evidence. *Philosophical Transactions of the Royal Societty B Biological Sciences*, 353(1373), 1257-1270. doi: 10.1098/rstb.1998.0281
- Hopf, J. M., & Mangun, G. R. (2000). Shifting visual attention in space: an electrophysiological analysis using high spatial resolution mapping. *Clin Neurophysiol*, 111(7), 1241-1257.
- Hopfinger, J. B., Buonocore, M. H., & Mangun, G. R. (2000). The neural mechanisms of topdown attentional control. *Nat Neurosci*, *3*(3), 284-291. https://doi.org/10.1038/72999
- Hopfinger, J. B., & Slotnick, S. D. (2020). Attentional Control and Executive Function. *Cognitive neuroscience*, *11*(1-2), 1–4.
- Ippolito, G., Bertaccini, R., Tarasi, L., Di Gregorio, F., Trajkovic, J., Battaglia, S. & Romei, V. (2022). The Role of Alpha Oscillations among the Main Neuropsychiatric Disorders in the Adult and Developing Human Brain: Evidence from the Last 10 Years of Research. *Biomedicines*. 10(12), 3189. https://doi.org/10.3390/biomedicines10123189

Itthipuripat, S., Cha, K., Byers, A., & Serences, J. T. (2017). Two different mechanisms support selective attention at different phases of training. *PLoS biology*, 15(6), e2001724. https://doi.org/10.1371/journal.pbio.2001724

James, W. (1890). The principles of psychology, Vol. 1. Henry Holt and Co.

- Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: Gating by inhibition. *Frontiers in Human Neuroscience*, 4. https://doiorg.proxy-ub.rug.nl/10.3389/fnhum.2010.00186
- Johnston, W. A., & Dark, V. J. (1986). Selective attention. *Annual Review of Psychology*, 37, 43-75.
- Jonides, J. (1981). Voluntary versus automatic control over the mind's eye. In J. Long & A. D. Baddeley (Eds.), *Attention and Performance IX* (pp. 187-203). Erlbaum.
- Jonides, J., & Irwin, D. E. (1981). Capturing attention. *Cognition*, 10(1-3), 145-150. https://doi.org/10.1016/0010-0277(81)90038-x
- Kastner, S., De Weerd, P., Desimone, R., & Ungerleider, L. G. (1998). Mechanisms of directed attention in the human extrastriate cortex as revealed by functional MRI. *Science*, 282(5386), 108-111. <u>http://www.ncbi.nlm.nih.gov/pubmed/9756472</u>
- Kastner, S., Pinsk, M. A., De Weerd, P., Desimone, R., & Ungerleider, L. G. (1999). Increased activity in human visual cortex during directed attention in the absence of visual stimulation. *Neuron*, 22(4), 751-761.
- Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences*, 16(12), 606–617. https://doi-org.proxyub.rug.nl/10.1016/j.tics.2012.10.007
- Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. J Exp Psychol Hum Percept Perform, 21(3), 451-468. http://www.ncbi.nlm.nih.gov/pubmed/7790827

- Lavie, N. (2005). Distracted and confused?: selective attention under load. *Trends Cogn Sci*, 9(2), 75-82. https://doi.org/S1364-6613(04)00316-X
- Lavie, N., & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Percept Psychophys*, 56(2), 183-197. http://www.ncbi.nlm.nih.gov/pubmed/7971119
- Lenartowicz, A., Kalar, D. J., Congdon, E., & Poldrack, R. A. (2010). Towards an ontology of cognitive control. *Top Cogn Sci*, 2(4), 678-692. <u>https://doi.org/10.1111/j.1756-</u> <u>8765.2010.01100.x</u>
- Liao, C. H., Worsley, K. J., Poline, J. B., Aston, J. A., Duncan, G. H., & Evans, A. C. (2002). Estimating the delay of the fMRI response. *Neuroimage*, *16*(3 Pt 1), 593-606. <u>https://doi.org/10.1006/nimg.2002.1096</u>
- Luck, S. J. (2014). *Introduction to the Event-Related Potential Technique* (2nd ed.). MIT Press.
- Luck, S. J., Chelazzi, L., Hillyard, S. A., & Desimone, R. (1997). Neural mechanisms of spatial selective attention in areas V1, V2, and V4 of macaque visual cortex. J Neurophysiol, 77(1), 24-42. <u>http://www.ncbi.nlm.nih.gov/pubmed/9120566</u>
- Luck, S. J., Vogel, E. K., & Shapiro, K. L. (1996). Word meanings can be accessed but not reported during the attentional blink. *Nature*, 383(6601), 616-618. <u>https://doi.org/10.1038/383616a0</u>
- Ma, D. S., Correll, J., & Wittenbrink, B. (2015). The Chicago face database: A free stimulus set of faces and norming data. *Behavior Research Methods*, 47, 1122–1135. https://doi. org/10.3758/s13428-014-0532-5
- Mangun, G. R., & Hillyard, S. A. (1991). Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming. J Exp Psychol Hum Percept Perform, 17(4), 1057-1074.

- Martinez, A., Anllo-Vento, L., Sereno, M. I., Frank, L. R., Buxton, R. B., Dubowitz, D. J., Wong, E. C., Hinrichs, H., Heinze, H. J., & Hillyard, S. A. (1999). Involvement of striate and extrastriate visual cortical areas in spatial attention. *Nat Neurosci*, 2(4), 364-369.
- Massironi, A., Lazzari, G., La Rocca, S., Ronconi, L., Daini, R., & Lega, C. (2024).
   Transcranial magnetic stimulation on the right dorsal attention network modulates the center-surround profile of the attentional focus. *Cerebral Cortex*, 34(2), 1–11.
- McAdams, C. J., & Maunsell, J. H. (1999). Effects of attention on orientation-tuning functions of single neurons in macaque cortical area V4. *J Neurosci*, *19*(1), 431-441.
- Meyyappan, S., Rajan, A., Mangun, G. R., & Ding, M. (2021). Role of Inferior Frontal Junction (IFJ) in the Control of Feature versus Spatial Attention. *J Neurosci*, 41(38), 8065-8074. <u>https://doi.org/10.1523/JNEUROSCI.2883-20.2021</u>
- Meyyappan, S., Rajan, A., Mangun, G. R., & Ding, M. (2022). Top-down control of the left visual field bias in cued visual spatial attention. *Cereb Cortex*.
- Miezin, F. M., Maccotta, L., Ollinger, J. M., Petersen, S. E., & Buckner, R. L. (2000). Characterizing the hemodynamic response: effects of presentation rate, sampling procedure, and the possibility of ordering brain activity based on relative timing. *NeuroImage*, *11*(6 Pt 1), 735–759. https://doi.org/10.1006/nimg.2000.0568
- Moerel, D., Grootswagers, T., Robinson, A. K., Shatek, S. M., Woolgar, A., Carlson, T. A. & Rich, A. N. (2022). The time-course of The time-course of feature-based attention effects dissociated from temporal expectation and target-related processes. *Sci Rep 12*, 6968. https://doi.org/10.1038/s41598-022-10687-x
- Moran, J., & Desimone, R. (1985). Selective Attention Gates Visual Processing in the Extrastriate Cortex. *Science*, *229*(4715), 782-784.

- Noah, S., Powell, T., Khodayari, N., Olivan, D., Ding, M., & Mangun, G. R. (2020). Neural mechanisms of attentional control for objects: Decoding EEG alpha when anticipating faces, scenes, and tools. *The Journal of Neuroscience*, 40(25), 4913–4924. https://doiorg.proxy-ub.rug.nl/10.1523/JNEUROSCI.2685-19.2020
- Noah, S., Meyyappan, S., Ding, M., & Mangun, G. R. (2022). Anticipatory attention is a stable state induced by transient control mechanisms. *Frontiers in Human Neuroscience*, 16. https://doi-org.proxy-ub.rug.nl/10.3389/fnhum.2022.965689
- Noah, S., Meyyappan, S., Ding, M., & Mangun, G. R. (2023). Time Courses of Attended and Ignored Object Representations. *Journal of Cognitive Neuroscience*, *35*(4), 645–658. https://doi.org/10.1162/jocn a 01972
- Norman, D. A. (1968). Toward a theory of memory and attention. *Psychological Review*, 75(6), 522–536. https://doi.org/https://doi.org/10.1037/h0026699
- Ogawa, S., Lee, T., Stepnoski, R., Chen, W., Zhu, X. & Ugurbil, K. (2000). An approach to probe some neural systems interaction by functional MRI at neural time scale down to milliseconds. *Proceedings of the National Academy of Sciences*, *97*(20), 11026-11031.
- Olshausen, B. A., Anderson, C. H. & Van Essen, D. C. (1993). A Neurobiological Model of Visual Attention and Invariant Pattern Recognition Based on Dynamic Routing of Information. *The Journal of Neurosciences*, 13(11), 4700-4719.
- Patel, G. A., & Sathian, K. (2000). Visual search: bottom-up or top-down? *Front Biosci*, *5*, D169-193. <u>http://www.ncbi.nlm.nih.gov/pubmed/10702378</u>
- Pfurtscheller, G., & Lopes da Silva, F. H. (1999). Event-related EEG/MEG synchronization and desynchronization: basic principles. *Clin Neurophysiol*, *110*(11), 1842-1857. <u>https://doi.org/10.1016/s1388-2457(99)00141-8</u>
- Poletti, M., Rucci, M., & Carrasco, M. (2017). Selective attention within the foveola. *Nat Neurosci*, 20(10), 1413-1417. <u>https://doi.org/10.1038/nn.4622</u>

- Posner, M. I. (1980). Orienting of attention. *Q J Exp Psychol*, *32*(1), 3-25. <u>http://www.ncbi.nlm.nih.gov/pubmed/7367577</u>
- Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *J Exp Psychol*, 109(2), 160-174. <u>http://www.ncbi.nlm.nih.gov/pubmed/7381367</u>
- Purokayastha, S., Roberts, M., & Carrasco, M. (2021). Voluntary attention improves performance similarly around the visual field. *Atten Percept Psychophys*, 83(7), 2784-2794. https://doi.org/10.3758/s13414-021-02316-y
- Quek, G. L., & de Heering, A. (2024). Visual periodicity reveals distinct attentional signatures for face and non-face categories. *Cerebral cortex (New York, N.Y. : 1991)*, 34(6), bhae228. https://doi.org/10.1093/cercor/bhae228
- Rajan, A., Meyyappan, S., Liu, Y., Henry Samuel, I. B., Nandi, B., Mangun, G. R., & Ding,
  M. (2021). The microstructure of attentional control in the dorsal attention
  network. *Journal of Cognitive Neuroscience*, 33(6), 965–983. https://doi-org.proxyub.rug.nl/10.1162/jocn a 01710
- Rashal, E., Santandrea, E., Ben-Hamed, S., Macaluso, E., Chelazzi, L., & Boehler, C. N. (2023). Effects of top-down and bottom-up attention on post-selection posterior contralateral negativity. *Atten Percept Psychophys*, 85(3), 705-717.
- Romei, V., Brodbeck, V., Michel, C., Amedi, A., Pascual-Leone, A., & Thut, G. (2008). Spontaneous fluctuations in posterior alpha-band EEG activity reflect variability in excitability of human visual areas. *Cereb Cortex*, *18*(9), 2010-2018.
- Rugg, M. D., Milner, A. D., Lines, C. R., & Phalp, R. (1987). Modulation of visual eventrelated potentials by spatial and non-spatial visual selective attention. *Neuropsychologia*, 25(1A), 85-96. https://doi.org/10.1016/0028-3932(87)90045-5

- Saalmann, Y. B., Pinsk, M. A., Wang, L., Li, X., & Kastner, S. (2012). The pulvinar regulates information transmission between cortical areas based on attention demands. *Science*, 337(6095), 753-756. <u>https://doi.org/10.1126/science.1223082</u>
- Sanders, A. F. (1966). Expectancy: application and measurement. *Acta Psychol (Amst)*, 25(4), 293-313. <u>https://doi.org/10.1016/0001-6918(66)90013-8</u>
- Slagter, H. A., Weissman, D. H., Giesbrecht, B., Kenemans, J. L., Mangun, G. R., Kok, A., & Woldorff, M. G. (2006). Brain regions activated by endogenous preparatory set shifting as revealed by fMRI. *Cogn Affect Behav Neurosci*, 6(3), 175-189. <u>http://www.ncbi.nlm.nih.gov/pubmed/17243354</u>
- Snyder, A. C., & Foxe, J. J. (2010). Anticipatory attentional suppression of visual features indexed by oscillatory alpha-band power increases: a high-density electrical mapping study. *J Neurosci*, 30(11), 4024-4032. <u>https://doi.org/10.1523/JNEUROSCI.5684-</u> 09.2010
- Spitzer, H., Desimone, R., & Moran, J. (1988). Increased attention enhances both behavioral and neuronal performance. *Science*, *240*(4850), 338-340.
- Szczepanski, S. M., Konen, C. S., & Kastner, S. (2010). Mechanisms of spatial attention control in frontal and parietal cortex. *J Neurosci*, *30*(1), 148-160.
- Tamber-Rosenau, B. J., Esterman, M., Chiu, Y. C., & Yantis, S. (2011). Cortical mechanisms of cognitive control for shifting attention in vision and working memory. *J Cogn Neurosci*, 23(10), 2905-2919. <u>https://doi.org/10.1162/jocn.2011.21608</u>
- Tootell, R. B. H., Hadjikhani, N., Hall, E. K., Marrett, S., Vanduffel, W., Vaughan, J. T., & Dale, A. M. (1998). The retinotopy of visual spatial attention. *Neuron*, 21(6), 1409-1422.
- Treisman, A. M. (1964). Selective Attention in Man. *British medical bulletin*, 20, 12–16. https://doi.org/10.1093/oxfordjournals.bmb.a070274

Tsotsos, J. K. (1990). Analyzing Vision at the Complexity Level. *Behavioral and Brain Sciences, 13*(3), 423-469.

Van der Heijden, A. H. C. (1992). Selective attention in vision. Taylor & Frances/Routledge.

- Van der Heijden, A. H. C., Schreuder, R., de Loor, M. & Hagenzieker, M. (1987). Early and late selection: Visual letter confusions in a bar-probe task. *Acta Psychologica* 65(1), 75-89.
- Van Moorselaar, D., & Slagter, H. A. (2020). Inhibition in selective attention. *Annals of the New York Academy of Sciences*, *1464*(1), 204–221. https://doi.org/10.1111/nyas.14304
- Van Voorhis, S., & Hillyard, S. A. (1977). Visual evoked potentials and selective attention to points in space. *Perception and Psychophysics*, *22*, 54-62.
- Vogel, E. K., Woodman, G. F., & Luck, S. J. (2005). Pushing around the locus of selection: evidence for the flexible-selection hypothesis. *J Cogn Neurosci*, 17(12), 1907-1922. https://doi.org/10.1162/089892905775008599
- Volpe, B. T., Ledoux, J. E. & Gazzaniga, M. S. (1980). Information Processing of Visual Stimuli in an 'Extinguished' Field. *Nature*. 282. 722-4.
- Wager, T. D., Jonides, J., & Reading, S. (2004). Neuroimaging studies of shifting attention: a meta-analysis. *Neuroimage*, 22(4), 1679-1693.
- Wannig, A., Stanisor, L., & Roelfsema, P. R. (2011). Automatic spread of attentional response modulation along Gestalt criteria in primary visual cortex. *Nat Neurosci*, 14(10), 1243-1244. <u>https://doi.org/10.1038/nn.2910</u>
- Wijers, A. A., Lamain, W., Slopsema, J. S., Mulder, G., & Mulder, L. J. (1989). An electrophysiological investigation of the spatial distribution of attention to colored stimuli in focused and divided attention conditions. *Biol Psychol*, 29(3), 213-245. <u>https://doi.org/10.1016/0301-0511(89)90021-5</u>

Woldorff, M. G., Hazlett, C. J., Fichtenholtz, H. M., Weissman, D. H., Dale, A. M., & Song,
A. W. (2004). Functional parcellation of attentional control regions of the brain. J *Cogn Neurosci*, 16(1), 149-165. <u>https://doi.org/10.1162/089892904322755638</u>

- Worden, M. S., Foxe, J. J., Wang, N., & Simpson, G. V. (2000). Anticipatory biasing of visuospatial attention indexed by retinotopically specific alpha-band electroencephalography increases over occipital cortex. *J Neurosci*, 20(6), RC63. http://www.ncbi.nlm.nih.gov/pubmed/10704517
- Wostmann, M., Stormer, V. S., Obleser, J., Addleman, D. A., Andersen, S. K., Gaspelin, N., Geng, J. J., Luck, S. J., Noonan, M. P., Slagter, H. A., & Theeuwes, J. (2022). Ten simple rules to study distractor suppression. *Prog Neurobiol*, 213, 102269. <u>https://doi.org/10.1016/j.pneurobio.2022.102269</u>
- Yoo, S. A., Martinez-Trujillo, J. C., Treue, S., Tsotsos, J. K., & Fallah, M. (2022). Attention to visual motion suppresses neuronal and behavioral sensitivity in nearby feature space.
   *BMC Biol*, 20(1), 220. <u>https://doi.org/10.1186/s12915-022-01428-7</u>