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Metacontrast masking of symmetric targets

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Abstract

Visual shape perception is affected by masking. One type of masking called metacontrast masking involves a briefly flashed target and a spatially adjacent mask that follows at varying stimulus onset asynchronies (SOAs). The strength of masking is measured by the decrease of the target's visibility as a function of SOAs. Aydin (2021) demonstrated that a masking function produced depends on the contrast polarity relationship between the target and mask stimuli. The typical U-shaped function is only present for same-polarity stimuli.

This study aims to replicate and extend Aydin's findings by examining symmetry in a metacontrast masking paradigm. As in the original study, we used asymmetrical discs with contour deletion on either the left or the right. Additionally, we used new symmetric stimuli, including discs with bilateral contour deletions, symmetric and asymmetric polygons, and complex "butterfly" stimuli with or without vertical symmetry. It is hypothesised that we will replicate the characteristic U-shaped function at intermediate SOAs, and a facilitation effect at 0 ms.

By employing these stimuli, this research intends to explore how symmetry influences masking effects. Symmetry is a prominent feature of the visual world, and it plays a role in many higher-level processes of visual perception. Investigating symmetry adds complexity to our understanding of masking phenomena and may reveal novel insights into visual perception mechanisms.

By replicating and extending Aydin's findings and investigating new stimuli, this study contributes to the growing body of literature on metacontrast masking and its implications for understanding visual perception phenomena.

Keywords Visual masking · Metacontrast · SOA · Symmetry

Introduction

Visual perception is a fundamental human ability that allows us to gather information from our environment and to make complex decisions. This strongly substantiates the need for comprehensive visual cognition studies. While many mechanisms within visual perception have been explicated, some remain elusive. One intriguing phenomenon in this domain is visual masking.

Visual masking has been pivotal in studying spatial and temporal properties of visual perception (Breitmeyer & Ogmen, 2006). ***Visual masking*** refers to the reduction or elimination of the visibility of one brief (≤ 50 ms) stimulus, called the “target”, by the presentation of a second brief stimulus, called the “mask” (Breitmeyer & Ogmen, 2007). The target can be obscured by either noise or structure. Noise masks are randomly scattered and disrupt target recognition without a structural relationship to the target. In contrast, structure masks share characteristics with the target and are spatially adjacent, creating contour contiguity.

Temporal and spatial variables influence target visibility, including shape, size, luminance, and timing parameters (Breitmeyer & Ogmen, 2007). The mask can precede the target’s onset, and in this case ***forward masking*** is observed. Conversely, when the target precedes mask’s onset, ***backwards masking*** occurs. Finally, ***simultaneous masking*** takes place if the target and the mask appear at the same time.

In our study, we focus on ***metacontrast masking***, a type of backward masking where a temporally proximal but spatially non-overlapping mask impairs the detection of a preceding target stimulus (Breitmeyer, 1984, as cited in Boyer & Ro, 2007).

The relationship between the target and mask is quantified by ***Stimulus Onset Asynchrony (SOA)***, which represents the time between the onset of the target and the onset of the mask. A ***masking function*** highlights the relation between the visibility of the target and the delay between the target and the mask (SOA). Visibility is measured by task performance (accuracy, latency), which reflects the amount of masking present. Thus, if we were to plot the function, the performance axis would be represented by the abscissa (y-axis), and the time – by the ordinate (x-axis).

The ***confusion hypothesis*** posits that if the mask is similar to the target stimulus, it would make the target difficult to perceive, identify, or discriminate as an *individual* stimulus relative to the *entire* stimulus consisting of both the target and the mask (Ogmen, 2019). According to this hypothesis, maximum masking should occur at an SOA of 0, and the strength of the masking—inversely proportional to the target's visibility—should decrease as SOA values move further from 0, resulting in either a monotonically decreasing or increasing function. This type of monotonic masking is referred to as “Type-A.” It is also often associated with a stronger masking stimulus. However, there is another masking function that the confusion hypothesis fails to account for, known as “Type-B,” “non-monotonic,” or more descriptively, a “U-shaped” masking function. In this case, the maxima do not occur at an SOA of 0 but rather at intermediate values along the abscissa. The task is easier to perform at short and long SOAs, which suggests a more complex interaction. This may be due to interruption effects, where the mask disrupts processing, or interchannel inhibition, where sustained signals from the mask interfere with target detection (Francis & Herzog, 2004).

The differences between the two masking functions have generated intense discussions on the theories and interpretations of masking. In a series of experiments, Kolers (1962) found out that Type A curves occur either with flashes of light as stimuli to the dark-adapted eye, or when the stimuli are small black forms presented to the light adapted eye. In contrast, Type-B curves emerge when the target and mask have similar contrast, size, and luminance, suggesting that U-shaped functions occur when the target and mask are closely matched in energy. The distinction between monotonic and non-monotonic functions reflects different mechanisms of masking: Type-A masking may involve early, feedforward processing where the target and mask integrate into a single stimulus. In contrast, Type-B masking might involve feedback processes that either interrupt—halting the processing of the target by the mask—or inhibit—where sustained signals from the mask interfere with the detection of target properties (Ogmen et al., 2003).

Ogmen et al. (2003) noted that the nature of the masking function depends on the stimulus dimension judged by the observer. For tasks evaluating surface properties, contour properties, or figural identity, a U-shaped masking function typically results. Conversely, tasks assessing presence or spatial location of the target are less affected by metacontrast masks, indicating a factor that influences the masking function.

Of interest in this paper is the phenomenon of backwards masking. An attempt to understand it would involve delving into two broad classes of conceptual models. One states that visual sensory information is stored in a visual sensory buffer (or iconic memory) for processing, but can be interrupted by a mask (Sperling, 1963; Di Lollo, 1980; as cited in Siverstein, 2015). The other states that information propagates in dual channels (such as parvocellular and magnocellular pathways), with one faster and more transient and the other slower and more sustained. When the target and mask are presented to both channels, the fast transient activity of the mask suppresses the slow sustained activity of the target through inter-channel inhibition (Silverstein, 2015). Computational studies have suggested that both lateral inhibition in early visual areas (V1 and V2) and feedback from higher visual areas contribute to masking effects. Feedback from V2 can reinforce the target pattern before lateral inhibition fully impacts it, thereby modulating the masking effect (Silverstein, 2015).

One of the main objectives of this study is to replicate the findings of Aydin (2021). In Aydin's experiment, participants viewed black or white discs with a unilaterally missing segment as target stimuli. These targets were paired with mask rings that varied in contrast polarity—either matching the target's polarity (same-polarity-contrast) or differing from it (different-polarity-contrast). The masks were presented at various Stimulus Onset Asynchronies (SOAs) to assess their effect on target visibility.

Results revealed a U-shaped masking function. Specifically, participants performed best at an SOA of 0 ms, where the target and mask appeared simultaneously. Performance at this point even surpassed that of the no-mask control condition. The masking effect was strongest at around 50 ms SOA, with accuracy declining as the SOA approached this point and improving at both shorter and longer delays.

This study aims to replicate these results and further explore how symmetry influences masking effects. We will introduce symmetric stimuli to determine whether symmetry affects the U-shaped function and contributes to changes in target visibility. The experimental setup is visualized in the Figure 1 below. By comparing these new conditions with Aydin's original setup, we hope to gain insights into the role of symmetry in visual masking.

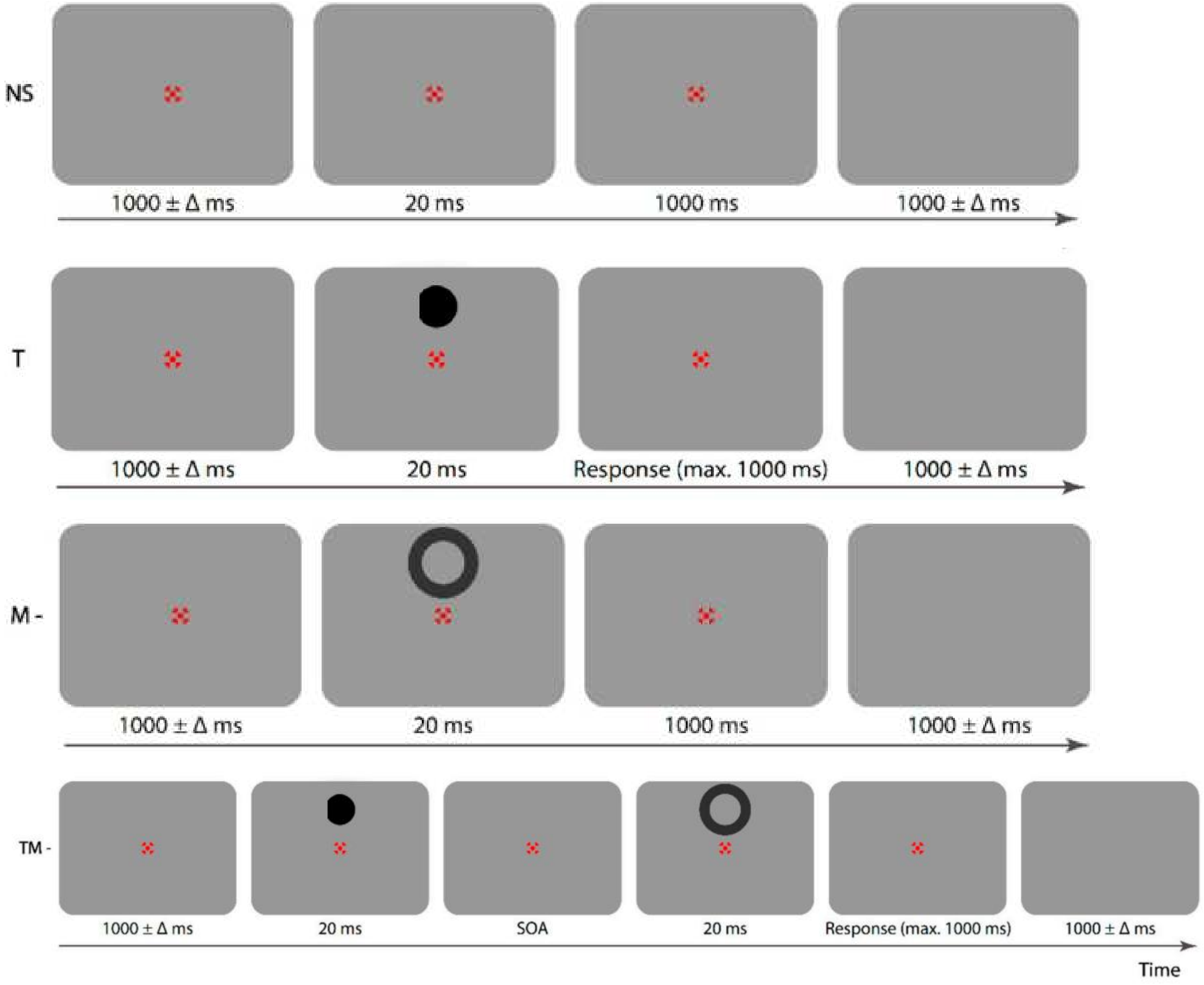

***Fig. 1**. Schematic representation of stimuli and timeline. The "single" condition was taken as an example.*

Symmetry is not an uncommon feature in visual perception but a fundamental aspect that aids in processing and understanding visual information. It is closely linked to the concepts of structure and regularity and helps the visual system recognize and distinguish objects from their background, which is particularly relevant to metacontrast masking. Disruptions in symmetry perception, such as when convexities on one side of an object correspond to concavities on the other (Mancini et al., 2017; as cited in Bertamini et al., 2018), underscore the importance of reflection symmetry in object recognition. Since symmetry often reflects natural structural patterns (Mancini et al., 2017; as cited in Bertamini et al., 2018), investigating its effects in the context of metacontrast masking can reveal how disruptions in symmetry influence the perception of visual structure and regularity.

In our study, we use stimuli with vertical reflectional symmetry, a type that is perceived effortlessly (Mach, 1897). Research shows that symmetry can be detected even with very brief presentations, such as 50 and 25 milliseconds (Markovic & Gvozdenovic, 2001; as cited in Bertamini et al., 2018), which fits well with our experimental design. Given the lack of literature specifically addressing symmetry within the metacontrast masking paradigm, our study aims to fill this gap and explore how symmetry impacts visual perception, particularly in situations involving competing visual stimuli.

Methods

Participants

Both experiment 1A and experiment 1B involved 21 participants each. The participant pool was mainly composed of students of the University of Padova. Experiment 1A had 17 female and 4 male participants, experiment 1B – 19 and 2 respectively. The age ranged from 20 to 23 inclusively for everyone in Experiment 1A. Participants of Experiment 1B were aged 20 to 24 inclusively, with the exception of two female subjects aged 35. Every volunteer had normal or corrected-to-normal visual acuity. Every subject was made aware of the experimental procedures and gave informed consent.

Apparatus

Participants were seated in a dimly lit room, in front of a 52.8 × 29.7 cm monitor. A chinrest was employed to fixate the distance from the screen at a 57 cm mark. The experiment was generated using PsychoPy. Eye movements were monitored with an eye tracker, and the stimulus was not presented if the participant looked away from the fixation point.

Stimuli

A red fixation target was presented at the centre of the screen at all points during the experiment. The target and mask were centred 3° above the fixation on the vertical meridian. In the first condition, we will call it the “single” condition for convenience, the target appeared as a disk of 1.5° diameter with a 0.15° wide right or left contour deletion. The mask ring had 1.55° inner and 2.55° outer diameters, and it surrounded the target disk. These parameters led to a target-mask separation of 0.05°. In the “double” condition, the target was either a disk of 1.5° diameter with a 0.15° wide right or left contour deletion or a disk with a 0.15° wide contour deletion on both sides (symmetric). The mask ring had 1.55° inner and 2.55° outer diameters, and it surrounded the target disk. In the “symmetry” condition, the target was a complex “butterfly” stimulus with or without symmetry along the vertical axis. The mask ring had 1.55° inner and 2.55° outer diameters, and it surrounded the target disk. The black target and the black mask had the same polarity, and were presented on a uniform grey background across all trials. The target and the mask stimuli had an equal duration of 20ms in Experiment 1A, and an equal duration of 30ms in Experiment 2A. The examples of all types of stimuli and stimuli-mask combinations are shown in the Figure 2 right below.

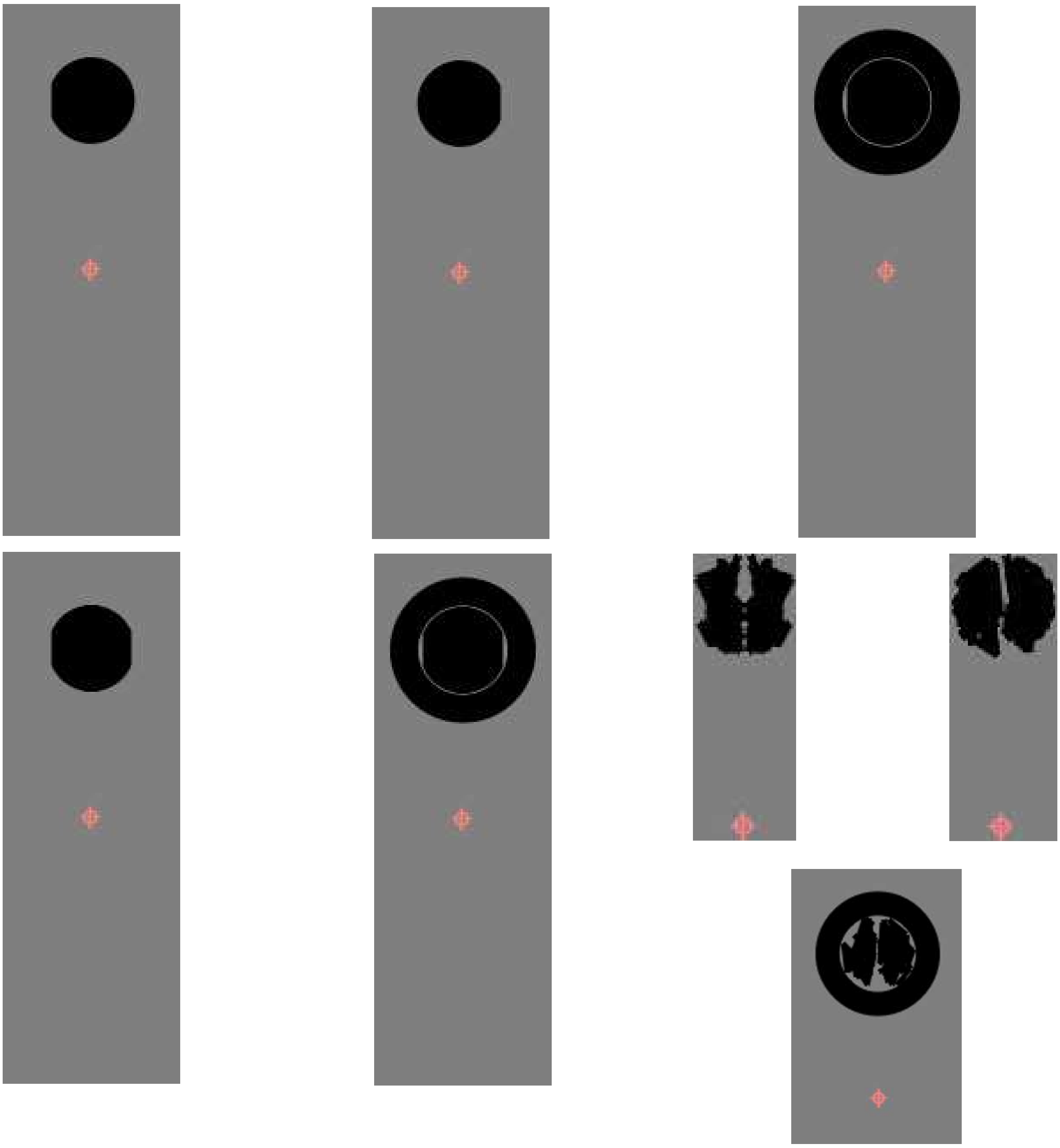

Fig. 2. Examples of target stimuli in the three conditions, and their combinations with a mask.

Design and procedure

Each experimental session had 3 conditions, they all consisted of a short practice session (40 trials) and a longer main session (200 trials). The practice session was introduced to accustom the participants to the experiment, and each response was followed with feedback (“correct”/ “incorrect”). No feedback was provided for the main session. For the entire duration of the experiment, the observer was instructed to maintain fixation on the red cross in the centre. We employed an eye tracker to ensure that this condition was fulfilled, as the presentation of the stimuli was discontinued when the observer deviated from the fixation target in the centre.

Before both the practice and main sessions, participants underwent a calibration process—twice per session—to ensure accurate eye-tracking. This calibration involved following a green dot moving across a uniform white background on the screen. The eye-tracking data was recorded for each trial. Prior to the experiment, participants were briefed on the procedures and shown sample stimuli to prepare them for the task.

To summarise, the sequence (calibration -> practice -> calibration -> experiment) was the same across all three conditions, and they all had the same number of trials for the practice and the main sessions of the experiment. The stimulus-onset-asynchronies (SOAs) varied from 0 (simultaneous presentation of stimulus and the mask) to 200 milliseconds.

During the “single” condition, the participant had to designate if the stimulus presented had a segment missing from the left or the right by pressing the left “←“ or the right “→” key on the keyboard respectively.

During the “double” condition, the participant had to respond if the stimulus shown had a segment deletion from one (either left or right) or two sides. The latter is essentially a symmetrical stimulus, and we wondered if symmetrical and non-symmetrical stimuli would be processed differently. If the disk had a unilateral segment deletion, the up “↑” key had to be pressed, if it had a bilateral – the down “↓” key.

During the “symmetry” condition, the participant had to differentiate between a complex “butterfly” stimulus with vertical symmetry and one with no vertical symmetry by pressing either the left “←“ key or the right “→” key on the keyboard respectively. Again, half of the stimuli were symmetrical and half were non-symmetrical.

Simple randomisation was used to randomly assign a participant to a possible sequence of the three conditions described above. Thus, a potential selection bias is prevented.

After the experiment’s completion, participants were explained the purpose and hypothesis of the experiment, based on the Aydin (2021) paper.

Data Analysis and Results

Experiment 1A (20ms Presentation Time)

Data Preparation and Cleaning

Data were analysed from three conditions: “symmetry”, “single”, and “double” stimuli presentations. Participants with an overall accuracy below **57.5%** were excluded. The final sample sizes were **17** (14 female and 3 male participants) for the “symmetry” condition, **14** (12 female and 2 male participants) for the “single” condition, and **7** (6 female and 1 male participants) for the “double” condition.

Data were categorized into ***Masked Trials*** - trials with a visual mask, and ***No Mask Trials*** - control trials without a mask. The analysis focused on masked trials.

Statistical Modelling

In terms of statistical analysis, we fitted a Generalized Linear Model (GLM) to the data to examine the relationship between Accuracy and SOA. Additionally, we performed an Analysis of Deviance (ANOVA) on the GLM to assess the significance of SOA as a predictor. The results are presented in the tables 1 and 2 below.

The average accuracy on the Masked Trials without exclusion of participants for the “symmetry” condition was **69.6%**, for the “single” condition – **70.0%**, for the “double” condition – **57.4%**. Clearly, this indicates that the “double" condition might have been too difficult for the participants.

Table 1. Generalized Linear Model (GLM) for Accuracy Exp. 1A

Condition	*“Symmetry”*	*“Single”*	*“Double”*
Model	Accuracy ~ SOA + SOA^2	Accuracy ~ SOA + SOA^2 + SOA^3 + SOA^4 + SOA^5	Accuracy ~ SOA^2 + SOA^3
Coefficients	SOA = 0.602 (SE = 0.123, **p < 0.0001**), SOA^2 = 0.367 (SE = 0.122, **p < 0.001**)	SOA = -0.885 (SE = 0.198, **p < 0.0001**), SOA^2 = 1.635 (SE = 0.200, **p < 0.0001**), SOA^3 = -0.996 (SE = 0.183, **p < 0.0001**), SOA^4 = 0.511 (SE = 0.161, **p < 0.001**), SOA^5 = -0.385 (SE = 0.144, **p < 0.001**),	SOA^2 = 0.809 (SE = 0.188, **p < 0.0001**), SOA^3 = -0.689 (SE = 0.187, **p < 0.0001**)

Model fit	Deviance = 3714.5, AIC = 3692.9	Deviance = 2870.9, AIC = 2765.4	Deviance = 1621.4, AIC = 1599.1

**Only the effects at least as significant as p < 0.001 were reported*

Table 2. ANOVA analysis Exp. 1A

Condition	*“Symmetry”*	*“Single”*	*“Double*
Model	Accuracy ~ SOA	Accuracy ~ SOA	Accuracy ~ SOA
Effects	Chi-square = 39.522, **p < 0.0001**	Chi-square = 123.560, **p < 0.0001**	Chi-square = 40.298, **p < 0.0001**

Results and Interpretation

“Symmetry” Condition: Accuracy increased with SOA, peaking around 160 ms before levelling off. The quadratic term indicates diminishing returns with increasing SOA. The overall accuracy was lower compared to the “single” condition, suggesting additional complexity due to processing symmetric versus asymmetric stimuli.

***“Single” Condition**:* Analysis revealed highly significant liner, quadratic and higher-order term effects, which indicates a complex relationship between SOA and accuracy. The baseline accuracy was the highest among all conditions, indicating less masking effect when symmetry was not a factor.

***“Double” Condition**:* This condition displayed significant quadratic and cubic effects, indicating a more complex interaction where accuracy increased initially but then exhibited fluctuations. This may reflect increased complexity in processing double deletions. However, any conclusions drawn might be flawed, as more than half of the participants’ data was excluded due to not meeting the cut-off mark of 57.5% accuracy.

Visualization: Plots illustrated the general trend of increased accuracy with SOA, with pronounced differences across conditions. The facilitation effect at 0ms was observed only in the single condition. The baseline (average accuracy of controls depicted by the dotted line) was the highest in the “single” condition, which did not require symmetric/asymmetric discrimination. None of the plots obtained conformed fully to the traditional Type-B masking function. The “single” condition is the closest at resembling a Type-B masking function. The “symmetry” condition produces a function more akin to a Type-A masking function, as performance mostly increases along the ordinate. The "Double" condition is characterised by a function that does not conform to either of the usual types, as accuracy dips at both intermediate and longer SOA values.

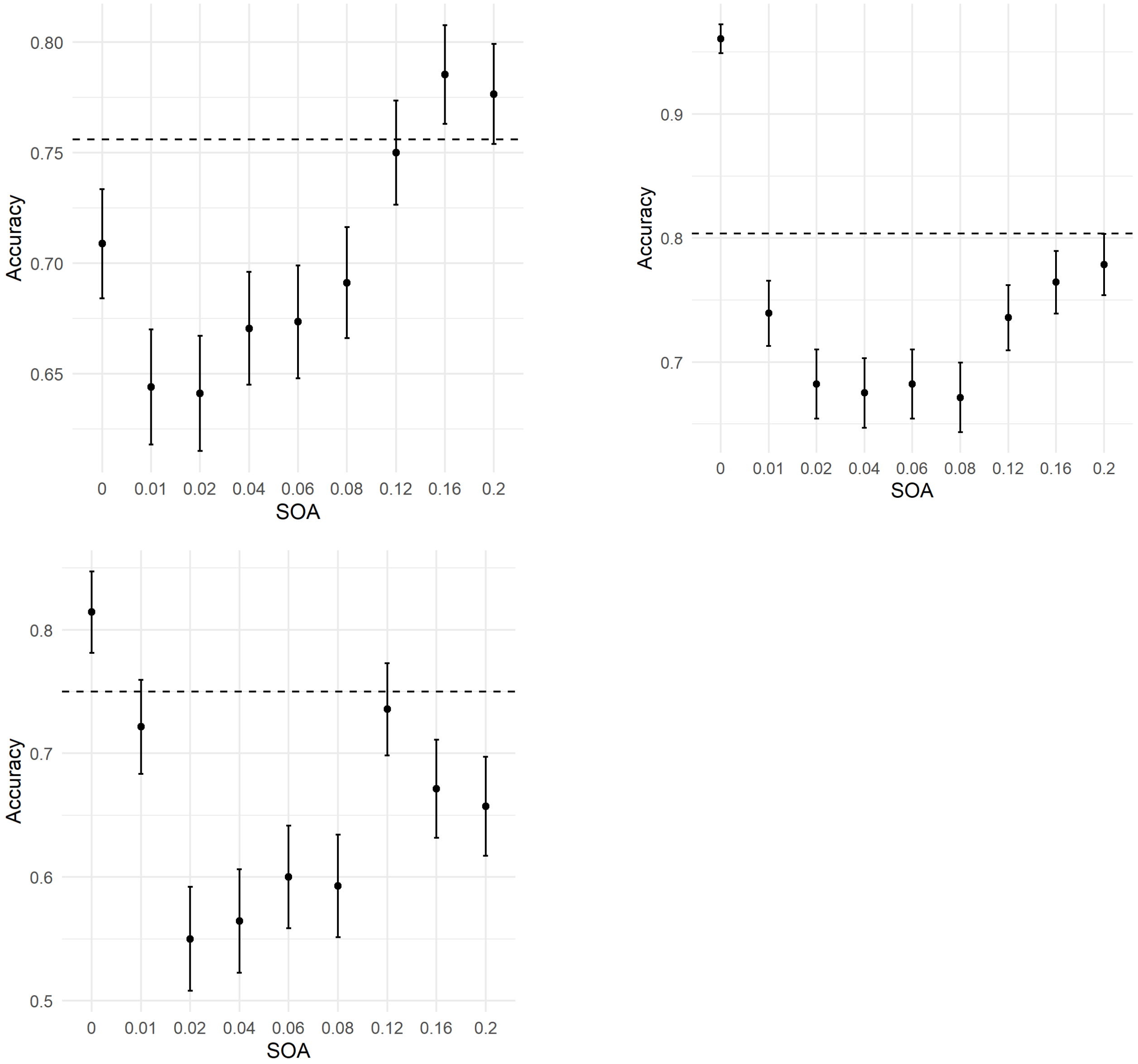

Fig.3. Masking strength as a function of SOA (seconds) for the "symmetry" (upper left), "single" (upper right), and "double" (bottom left) conditions of Experiment 1A.

Experiment 1B (30ms Presentation Time)

The results of Experiment 1A did not completely align with our hypothesis, leading us to speculate that the task conditions might have been too challenging for the expected U-shaped masking function to emerge. Especially concerning was the number of participants excluded in the "double" condition. To address this, we designed and conducted a follow-up experiment that was identical in every way except for the presentation time, which we extended to 30 ms. This adjustment aimed to reduce cognitive load, though it introduced the possibility of influencing the results in a more complex manner than simply increased presentation time leading to improved performance.

Data Preparation and Cleaning

Experiment 1B had the same design as Experiment 1A but with a 30ms stimulus presentation duration and a different participant pool. Participants with an overall accuracy below **57.5%** were excluded. The final sample sizes were **16** (14 female and 2 male participants) for the “symmetry” condition, **15** (13 female and 2 male participants) for the “single” condition, and **11** (9 female and 2 male participants) for the “double” condition.

Data were categorized into ***Masked Trials*** - trials with a visual mask, and ***No Mask Trials*** - control trials without a mask. The analysis focused on masked trials.

Statistical Modelling

Again, we fitted a Generalized Linear Model (GLM) to the data to examine the relationship between Accuracy and SOA, and then performed an Analysis of Deviance (ANOVA) on the GLM to assess the significance of SOA as a predictor. The results are presented in the tables 3 and 4 below.

The average accuracies on the Masked Trials without exclusion of participants were equal to **70.5%** for the “symmetry” condition, **72.9%** for the "single” condition, and **60.1%** for the "double” condition. Evidently, the “double” condition once again proved to be most challenging for the participants of the study.

Table 3. Generalized Linear Model (GLM) for Accuracy Exp. 1B

Condition	*“Symmetry”*	*“Single”*	*“Double”*
Model	Accuracy ~ SOA	Accuracy ~ SOA + SOA^2 + SOA^3 + SOA^4 + SOA^5	Accuracy ~ SOA^2 + SOA^3
Coefficients	SOA = 0.592 (SE = 0.129, **p < 0.0001**)	SOA = - 1.103 (SE = 0.260, **p < 0.0001**), SOA^2 = 2.078 (SE = 0.264, **p < 0.0001**), SOA^3 = -1.649 (SE = 0.232, **p < 0.0001**), SOA^4 = 0.720 (SE = 0.189, **p < 0.0001**), SOA^5 = -0.666 (SE = 0.154, **p < 0.0001**),	SOA^2 = 1.371 (SE = 0.167, **p < 0.0001**), SOA^3 = -0.868 (SE = 0.161, **p < 0.0001**)

Model fit	Deviance = 3422.2, AIC = 3404.8	Deviance = 3062.7, AIC = 2899.9	Deviance = 2578.4, AIC = 2479.9

**Only the effects at least as significant as p < 0.001 were reported*

Table 3. ANOVA analysis for Exp. 1B

Condition	*"Symmetry"*	*"Single"*	*"Double*
Model	Accuracy ~ SOA	Accuracy ~ SOA	Accuracy ~ SOA
Effects	Chi-square = 35.34, **p < 0.0001**	Chi-square = 180.79, **p < 0.0001**	Chi-square = 116.54, **p < 0.0001**

Results and Interpretation

"Symmetry" Condition: Accuracy improved with SOA, reaching higher levels at extended SOAs, exhibiting a strong linear trend.

"Single" Condition: Analysis revealed highly significant linear, quadratic and higher-order term effect. This implies that there is a highly complex, non-linear relationship between SOA and accuracy.

"Double" Condition: Showed improvement with SOA, with quadratic and cubic effects indicating a more complex relationship. The higher baseline accuracy compared to Experiment 1A suggests that longer stimulus duration mitigated some of the cognitive demands. However, 7 observers' data still had to be excluded from the analysis.

Visualization: Plots depicted performance improvement with SOA across conditions, with symmetry and double conditions exhibiting more complex curves compared to the linear trend observed in the single condition. The facilitation effect at 0ms was observed for both the "single" and "double" conditions. None of the plots obtained conformed fully to the typical U-shaped masking function. The "Symmetry" condition has generated a function that generally showed a monotonically increasing trend (Type-A) along the ordinate. While the "single" condition's plot does exhibit a slight dip at an intermediate SOA, it is not profound and there is a smaller dip at a longer SOA as well. In the "Double" condition, the plot exhibited some characteristics of a U-shaped function, with a dip at intermediate SOAs and an increase in accuracy with longer SOAs. However, the accuracy at shorter SOAs did not decrease to the same extent.

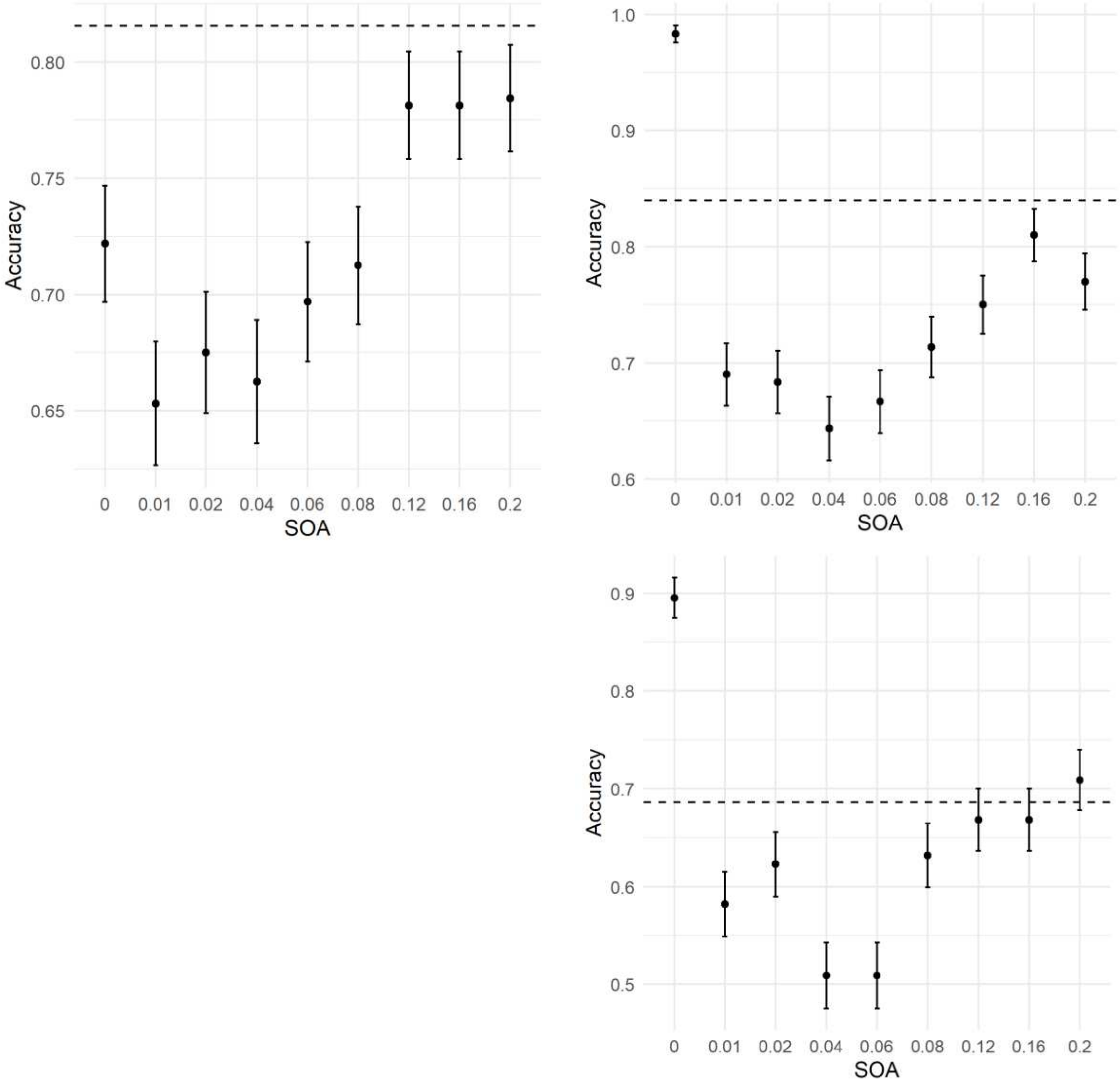

Fig.15*. Masking strength as a function of SOA (seconds) for the "symmetry" (upper left), "single" (upper right), and "double" (bottom left) conditions of the Experiment 1B.*

Discussion

Comparison between the Experiments 1A and 1B

The increase in stimulus presentation time from 20 ms to 30 ms resulted in overall higher accuracy across all conditions, indicating reduced masking effects. In the "symmetry" condition, accuracy generally increased with SOA, deviating from the classic U-shaped function. The "single" condition displayed a slight dip at intermediate SOAs, and the "double" condition showed a complex pattern with a partial U-shape. Notably, the “symmetry” condition showed the least change in mean accuracy (from 69.4% to 70.5%), possibly reflecting the high cognitive load required to process symmetrical stimuli. These findings align with Perceptual Load Theory, which posits that higher cognitive load reduces the efficiency of separating signal from noise, leading to stronger masking effects (Stolte, 2013).

SOA and Masking

The value of SOA established itself as a strong predictor of accuracy across all conditions in Experiments 1A and 1B, with its influence varying significantly depending on the stimulus type and complexity. A linear effect would suggest that as the time between the target and mask increased, participants will be better able to process and accurately identify the target. It was found consistently in both “symmetry” and “single” conditions of both experiments. However, a significant linear effect was not found in the “double” condition. Instead, it was consistently characterised by cubic and quadratic effects, making the relationship between SOA and accuracy less straightforward. It could be because of the complex and symmetric nature of stimuli. It remains unclear whether these effects are primarily due to the symmetric nature of the stimuli or simply a result of increased cognitive load. This suggests two possibilities: symmetry might inherently require more cognitive resources to process, or it might interact with SOA in a way that exacerbates the complexity of the task, leading to more variable performance outcomes.

Expanding on this, it should be noted that reflective, or mirror symmetry is known to be detected preattentively (Wagemans, 1997), even when participants are not explicitly asked to identify it. Moreover, among all types of symmetry, human visual perception has a strong preference for reflectional symmetry along the vertical axis, which is exactly the one displayed in the stimuli used in this study.

Given this preattentive detection capability, it would be inaccurate to suggest that symmetry inherently requires more cognitive resources. Instead, it is more plausible that symmetry interacts with SOA in a way that amplifies the complexity of the task, rather than simply increasing cognitive load. This interaction likely contributes to the cubic and quadratic effects observed in the "double" condition, and quadratic effects seen in the “symmetry” condition. These findings suggest that while symmetry is easily detected, the integration of this information under varying SOA conditions introduces complexities that affect performance in non-linear ways.

Notably, the anticipated U-shaped masking function was not observed consistently. This suggests that the interplay between stimulus complexity and SOA is more nuanced than initially anticipated. The facilitation effect at 0 ms SOA, where performance briefly improves due to the integration of the target and mask (confusion hypothesis), was only replicated in the “single” condition of Experiment 1A and the “single” and “double” conditions of Experiment 1B. The absence of this effect in the “double” condition of Experiment 1A likely stems from the high cognitive demands imposed by the task, which overwhelmed participants' processing capacities. In the “symmetry” condition, the lack of facilitation may be due to the greater contour discontinuity between the target and mask, likely preventing the integration of the two stimuli into a single perceptual event.

In addition, these findings align with the broader literature on visual processing, where global and local processing mechanisms are known to differentially affect how stimuli are perceived under various temporal conditions (Navon, 1977). Specifically, the stimuli employed in “single” and “double” conditions, where participants were required to focus on absence or presence of small laterally missing segments, engaged primarily in local processing mechanisms. Those could have introduced more complexity in the SOA-accuracy relationship as local processing can be sensitive to small changes in stimulus features or timing. On the contrary, “symmetry” condition utilised stimuli that engaged global processing mechanisms. Global processing, which integrates information across the entire visual field to perceive overall structures or patterns, tends to smooth out the effects of small variations in the stimulus, often leading to a more straightforward, linear relationship between SOA and accuracy. Understanding these dynamics is crucial for advancing our knowledge of how visual information is integrated over time, especially in conditions involving complex stimuli.

The findings in the "double" condition, where accuracy improved with SOA but showed a complex, non-linear pattern, align with the dual-channel model of visual processing. According to this model, fast, transient signals from the mask may interfere with the slower, sustained processing of the symmetric target, particularly when the SOA is short. The significant quadratic and cubic effects observed in both experiments support this idea, indicating that the additional time provided by longer SOAs may allow for more effective integration of symmetrical information. This is consistent with the notion that symmetry detection, while often preattentive, may require more cognitive resources when combined with competing visual information.

Both the GLM and ANOVA revealed a significant linear trend in the “symmetry” condition. This indicates a simpler visual processing mechanism. This finding aligns with the traditional feedforward processing model, where target visibility improves as the mask's inhibitory effect on early visual areas (e.g., V1 and V2) weakens with increased SOA. The absence of linear effects in the “double” condition, contrasted with the strong linear effects in the “symmetry” condition, might highlight important differences between these stimuli, even though both exhibit reflectional symmetry along the vertical axis. Speculatively, it could be the result of the variations in cognitive load, differences between local and global processing, or the extent of contour discontinuity affecting the integration of the target and mask.

Overall, these findings enhance our understanding of how visual complexity, symmetry, and SOA interact in metacontrast masking. By revealing how symmetry influences masking effects, particularly through non-linear interactions, this research challenges existing models of metacontrast masking. This research underscores the need to consider both stimulus characteristics and temporal dynamics in studies of visual perception.

Limitations

It is important to consider the limitations of the study in order to estimate the strength of the results and to identify directions for future research. The first limitation concerns the homogeneity of the participants pool, with a predominance of female participants and a narrow age range. This lack of diversity limits the generalisability of the findings.

Secondly, a notable number of participants had to be excluded from the analysis due to the accuracy cut-off criteria, especially in the “double” condition. This exclusion led to imbalanced sample sizes across conditions, potentially affecting the reliability of the findings and our understanding of how different stimuli interact with SOA. This disparity could also undermine the overall robustness of the conclusions.

Symmetry is not a factor commonly explored in metacontrast masking paradigm, which certainly makes this study unique. However, it also means that symmetric stimuli that were not previously employed in metacontrast masking could have introduced unanticipated variables.

Although we tested two different presentation times (20 ms and 30 ms), there may be other optimal presentation times that were not explored in this study. Thus, broadening the presentation time range could be an improvement.

Finally, the complexity of the stimuli and their interaction with SOA led to non-linear effects which were challenging to interpret. This complexity might have obscured the true nature of the masking effects.

Additional Experiments

Given the limitations and unexplored aspects of the metacontrast masking paradigm in our initial study, two additional experiments were planned. The stimuli used in the “symmetry” condition failed to produce a U-shaped masking function or a facilitation effect at 0 ms, they were also found to be particularly challenging for participants.

To address these issues, a novel experiment was designed with two primary objectives: (1) to determine whether a different set of stimuli would yield more effective results compared to the complex “butterfly” stimuli, and (2) to reduce cognitive load by presenting stimuli in the fovea rather than the parafovea. The new stimuli consisted of regular (symmetric) and irregular (asymmetric) polygons, created in a way that would minimize contour discontinuity when masked. An example is shown in Figure 4.

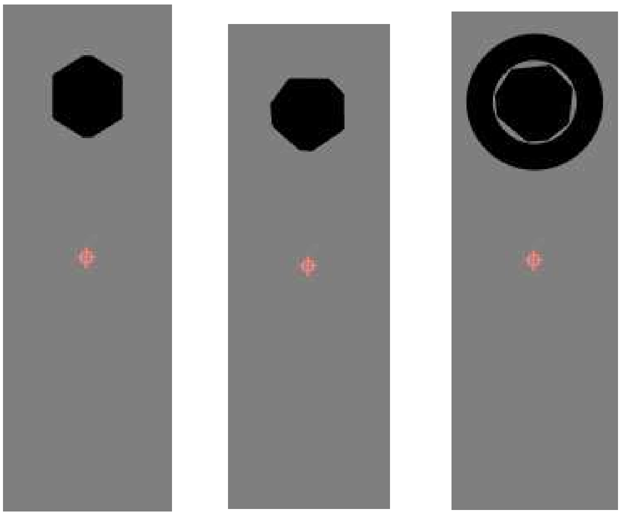

***Fig. 4**. Examples of the stimuli in Exp. 2*

This experiment consisted of three conditions: 1) discrimination between symmetric and asymmetric polygons presented in the fovea; 2) discrimination between symmetric and asymmetric polygons presented in the parafovea; 3) discrimination between symmetric and asymmetric “butterfly” stimuli presented in the fovea.

The goal was to identify the optimal experimental condition, which could result in one of the following scenarios: a) using the “butterfly” stimuli in the fovea; b) utilising new stimuli in the parafovea; c) using new stimuli in the fovea.

Additionally, a separate study is planned to explore the neural correlates of metacontrast masking for both symmetric and asymmetric targets. Participants will undergo the experimental procedures from the initial study while wearing an elastic cap equipped with scalp electrodes to record EEG signals. This study aims to record and analyse ERP components for each condition, providing deeper insights into the neural mechanisms underlying metacontrast masking.

Conclusion

In closing, this research contributes to understanding of visual perception by examining the interplay of stimulus complexity, symmetry, and stimulus-onset asynchrony (SOA) on metacontrast masking. Findings demonstrate that longer presentation times improve accuracy, and that symmetry's interaction with SOA introduces profound complexities into masking effects. Although there are some challenges posed by stimulus complexity and participant homogeneity, findings of this study are still valuable in terms of understanding the dynamics of visual processing. Future studies should be focused on unravelling the interactions between visual stimuli characteristics, cognitive load, and neural processing mechanisms. These investigations will contribute to strengthening theoretical models of visual processing and possibly lead to important practical applications in the fields where understanding of intricacies of visual processing is crucial, such as Human Computer Interactions (HCI) or visual ergonomics.

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