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**Analisi di stimoli non sociali con caratteristiche
di contrasto asimmetrico simili allo sguardo**

Analysis of non-social stimuli with similar
asymmetrical contrast features of eye-gaze stimuli

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PREFACE

This thesis is the result of a research study conducted at the Mind, Brain, and Behavior Research Center (CIMCYC) at the University of Granada, within the Social Attention Laboratory, under the supervision of Professor Juan Lupiañez, head of the laboratory and an expert in cognitive neuroscience and attention mechanisms.

The study is part of a broader research project investigating the cognitive and attentional processes underlying social perception and interaction. Specifically, my experiment focuses on the role of contrast characteristic between the pupil and the sclera within attentional process using different types of arrows.

The research is grounded in the theoretical models of attention and social cognition, exploring how individuals process and respond to social and non-social stimuli in controlled experimental conditions. The study employs behavioral computer tasks measuring reaction time and accuracy, allowing for a detailed examination of the mechanisms involved in attention.

This experience has been invaluable in deepening my understanding of experimental psychology and cognitive neuroscience methodologies. Working within the CIMCYC has provided me with the opportunity to collaborate in an international and multidisciplinary research environment, further strengthening my analytical and research skills.

I am grateful to Professor Juan Lupiañez for his guidance and support throughout this project, as well as to the research team at the Social Attention Laboratory for their collaboration and insights.

ABSTRACT

Eye-gaze plays a crucial role in social interactions and may activate different attentional orienting mechanisms compared to non-social cues. By using a spatial interference paradigm, it has been observed that arrows result in faster reaction times in congruent than incongruent trials, facilitating a standard congruency effect (SCE). In contrast, eye-gaze results in faster reaction times in incongruent than congruent trials, producing a reversed congruency effect (RCE)—a pattern potentially driven by the social significance of gaze processing. This reversion might be facilitated by the social significance of gaze processing. Additionally, from a distributional perspective using the conditional accuracy function (CAF), social targets elicited higher error rates for congruent than incongruent trials with social stimuli were observed within the fastest responses. Both congruent and incongruent trials showed reduced accuracy in the first bins. These patterns differ from those observed with non-social stimuli, which typically exhibit higher error rates for incongruent trials in the fastest responses, with such differences diminishing across the distribution.

Based on these observations, we aimed to examine the hypothesis that the dissociations observed with reaction times and the CAF tool with gaze are due to the incongruent location of the salient sclera (opposite to the less salient pupils of the eyes). To test this, we adapted non-social stimuli to have a contrast pattern similar to eye-gaze. We used two types of arrow targets: Eyes-like (darker, less salient on the target arrowhead) and Anti-Eyes-like (darker, less salient on the arrow tail) arrows (Experiment 1) and the same two target types embedded in a mosaic background (Experiment 2). Our results revealed no reversion for both target types, showing the SCE independently of the contrasting features. Additionally, no dissociation was observed with the CAF; both Eyes-like and Anti-Eyes-like arrows showed similar patterns, aligning with traditional non-social stimuli in distributional analysis studies. This suggests that the reversion is not elicited by the contrasting perceptual features of the stimuli, and the social nature of the stimuli gaze processing might underlie the reversions, as suggested in previous studies. observed with RTs and accuracy.

Key words: Social attention, arrows vs. eye-gaze, spatial stroop, conditional accuracy function, reversed congruency effect, background.

CHAPTER 1 - SOCIAL ATTENTION

1.1 Social attention

Social attention refers to the cognitive process through which individuals focus on and prioritize social cues in their environment. It involves directing one's attention towards social stimuli such as faces, body language, gestures, vocal expressions, and other social signals. Social attention plays a crucial role in social interaction, communication, and understanding others' intentions, emotions, and mental states (Baron-Cohen et al., 1997).

The research in the field of social attention has arisen from our interest in the mental states of others. While there are several cues to the direction of another person's attention (head position, body position, pointing gestures), the gaze direction holds a unique significance as an attentional cue (Birmingham & Kingstone, 2009). For instance, the gazes of others are a channel through which humans can communicate socially relevant information (Marotta et al., 2018) and they are a way to assess an individual's interests in their internal and external environments (Emery, 2000).

Eye-gaze provides valuable insights into the thoughts and feelings of others, serving as a key component in social interactions (Baron-Cohen et al., 1997; Emery, 2000). Due to its importance in social contexts, some researchers have suggested that eye-gaze, when functioning as attentional cue, might activate differential attentional orienting mechanisms when comparing to non-social cues, such as arrows (e.g., Friesen & Kingstone, 1998; Langton & Bruce, 1999). Therefore eye-gaze has been employed as a cue in several studies on attentional paradigms (e.g., Marotta et al., 2018).

From a developmental perspective, social attention includes many different aspects that develop during growth. The face processing in infancy is a crucial

process for social interactions and understanding the social environment. Newborns begin to develop facial recognition abilities within the first weeks of life, with an innate preference for human faces over other visual stimuli. By the first few months, infants become particularly sensitive to faces, with an increasing ability to distinguish between facial expressions and respond to visual cues such as eye contact (Valenza et al., 1996). They learn to follow an interlocutor's gaze between 2 and 4 months and they tend to focus longer on faces with open eyes compared to those with closed eyes (Çetinçelik et al., 2021).

A crucial aspect of social development and face processing is the phenomenon of joint attention. It involves the ability to share attention with another person towards the same object, event, or topic (Tomasello, 1995). Joint attention is achieved by using eye gaze, gestures, and vocalizations and emerges around 6 months (Bakeman & Adamson, 1984). This ability is crucial for both language and social development, and in its absence, infants may experience deficits in word learning. Indeed, there is a correlation between joint attention and vocabulary size. Additionally, children who demonstrate strong joint attention abilities tend to exhibit better language skills and social competence later in life (Tomasello & Todd, 1983).

Joint attention typically involves three key components: Initiating Joint Attention (IJA), Responding to Joint Attention (RJA) and Shared Attention. The IJA component refers to the ability of an individual to direct the attention of others towards an object or event by using gestures, vocalizations, or eye contact (Mundy et al., 2007). RJA involves of infants' ability to follow the direction of the gaze and gestures of others in order to share a common point of reference (Mundy & Jarrold, 2010). Finally the shared attention occurs when two or more individuals focus their attention on the same object or event simultaneously, it involves a mutual awareness and understanding of each other's attentional focus (Siposova & Carpenter, 2019).

Moreover, the social interactions that are enabled by joint attention led infants figure out the emotions, desires, and intentions of their social partners (Meltzoff

& Moore, 1998). These skills are associated with the development of theory of mind, namely, the ability to attribute mental states -beliefs, intentions, desires, knowledge, etc.- to oneself and others, and to understand that others may have beliefs, desires, intentions, and perspectives different from one's own (Corbetta et al., 2008; Gallagher & Frith, 2003). It's essentially the capacity to comprehend that individuals have thoughts, feelings, and intentions that influence their behaviors (Baron-Cohen, 2001). Theory of mind is one of the fundamental capacities that distinguishes human beings (Whiten, 1993), it is considered a crucial aspect of social cognition and plays a fundamental role in various aspects of human behavior, including communication, social relationships, and moral reasoning.

Furthermore, in line with previous studies, children with autism exhibit deficits in theory of mind and joint attention, highlighting difficulties in social communication. For example, they fail to recognize mental states such as thinking, desire, reference, and goals from a person's direction of gaze (Baron-Cohen et al., 1997). This is closely related to the significant influence of eye gaze on visual attention, which forms the basis for advanced social abilities such as theory of mind, language development, and cultural assimilation. Similarly, in contrast to typically developing children, infants diagnosed with Autism Spectrum Disorder (ASD) demonstrate diminished attention towards people and manifest impairments in social and communication skills (Swettenham et al., 1998). They struggle to comprehend that the gaze behavior of others allows one to infer the intentions and desires of mentalistic agents, instead utilizing gaze on a more superficial level (Baron-Cohen et al., 1995). Overall, the limited theory of mind abilities observed in individuals with autism has led Baron-Cohen (2001) to propose that individuals with autism exhibit a general deficit in empathizing skills.

Our gaze holds significant importance in social cognition, which refers to how we perceive, interpret, and understand social cues and interactions, allows us to acquire information from the environment and simultaneously signal back toward it (Jarick & Kingstone, 2015). From a very early age, infants demonstrate a unique

sensitivity to the faces of others and they learn quickly that the looking behaviors of others transmit significant information. The results of Farroni et al. (2002) provided converging evidence suggesting enhanced neural processing of direct gaze (i.e., faces directing their gaze straight-on to the viewers). In general, infants show a distinctive preference for faces, especially for the eyes, and soon later for the gaze direction of the others. As indicated above, all of this is connected to joint attention, theory of mind and social cognition.

From an evolutionary point of view, the significance of detecting eye-gaze has resulted in humans prioritizing communication over camouflage. This has led to the development of higher eye contrast morphology compared to non-human primate eyes (Kobayashi & Kohshima, 1997). The structure of the human eye distinguishes itself from other primates due to its distinctive combination of a white sclera surrounding a darker iris and pupil. The gaze possesses a unique morphology that we are primed to recognize from an early age; indeed, eye direction is particularly simple to detect due to the shape of the eye (Batki et al., 2000). The findings of Hietanen et al. (2008) showed that gaze direction also affects subjective ratings of emotional arousal and valence highlighting eye contact leads to increased them. We are inclined evolutionarily to follow the direction of others' gaze, and thus we are able to determine the precise direction of another's attention, an important capacity of human beings.

1.1.1. The neural correlates of social attention

Human beings possess extraordinary social skills. Social attention is transmitted primarily by gaze, but also by head and body orientation, each showing distinct neural mechanisms (Nummenmaa & Calder, 2009).

Greene and colleagues (2009) compared the neural activity involved in social orienting with that of nonsocial orienting using a spatial cueing task. The task included social cues (gaze) and automatic nonsocial cues (peripheral squares) presented at short and long stimulus onset asynchronies (SOA). Their results suggested the presence of subcortical mechanisms for nonsocial orienting and predominantly cortical mechanisms for social orienting. The findings of this

research carry important evolutionary implications. With social interactions, especially regarding eye gaze, becoming progressively crucial over time, they hypothesized that the development of the social orienting system occurred later in evolution compared to nonsocial automatic orienting.

Furthermore, it has been a research on two split-brain patients to investigate the neural mechanism underlying social orienting (Kingstone et al., 2000). Their findings, align with previous research (e.g., Calder et al., 2002; Haxby et al., 2000; Kanwisher et al., 1997), confirmed that gaze and face processing are preferentially lateralized to the right hemisphere. In addition, they suggested a difference response between the temporal and parietal lobes. The temporal cortex processes face and gaze information, while the parietal cortex is responsible for orienting spatial attention based on this information. These conclusions find confirm in both nonhuman primate investigations (Harries & Perrett, 1991) and functional neuroimaging analyses (Haxby et al., 1999; Wicker et al., 1998) suggesting in gaze direction activate temporal and parietal cortices.

A brain region known as the STP area in the cortex surrounding the superior temporal sulcus (STS) is known for its selectivity to facial stimuli in monkeys (Perrett et al., 1982). This cortical area is a convergent point for the dorsal and ventral visual streams.

The STS exhibits connections with the amygdala and the orbitofrontal cortex, regions known for their involvement in processing socially and emotionally significant stimuli in primates, both human and nonhuman (Puce & Perret, 2003). Additionally, the STS has face-specific cells and sensitivity to motion information. Recent discoveries suggest that alongside facial characteristics like mouth shape and gaze direction, visual cues regarding the form and position of fingers, hands, arms, legs, and torso also influence the tuning of STS cells (Desimone et al. 1984).

According to Baron-Cohen (1995), the STS in conjunction with the limbic system and the orbitofrontal cortex are involved in social cognition. A crucial element of social cognition is the identification of the direction of another's attention from

their direction of gaze or head view (Emery et al., 2000). In this regard, Haxby and colleagues (2000) proposed a neural model of face processing, which includes the inferior occipital gyrus, the fusiform gyrus, and the posterior part of the superior temporal sulcus (pSTS). These parts together form the "core system," a system capable of analyzing/processing different parts of the face contributing to the formation of cognitive representations of faces.

Neuropsychological research has shown that a number of brain regions are involved in different aspects of gaze interpretation. Carlin and Calder (2013) demonstrated that the anterior part of the STS is responsive to the direction of gaze. Indeed, the posterior part of the STS is involved in joint attention and theory of mind, underscoring its crucial role in the processing of social information and significant biological movement.

Regarding the difference in brain activation between social and non-social stimuli, the findings are inconclusive (Narganes-Pineda et al., 2023). For instance, Kingstone et al., (2004) conducted a study where participants were presented with an ambiguous image resembling either a face with directional eye cues or a car with headlights. Brain activation occurred when participants interpreted the image as a face but not as a car, despite both stimuli inducing equivalent attentional orientation at the behavioral level. Functional magnetic resonance imaging (fMRI) results indicated specific activation in the superior temporal sulcus (STS) in response to eye movement and gaze changes, suggesting its role in processing socially relevant information.

However, the exclusivity of STS involvement in gaze processing has been questioned. For example, Tipper et al., (2008) also investigated an ambiguous central signal, which could be perceived as either an arrow or an eye. Their findings revealed overlapping brain activation patterns for both signals, particularly in fronto-parietal regions associated with the dorsal and ventral attention networks. Additionally, occipital and frontal regions within the ventral network exhibited stronger responses to signals interpreted as eyes compared to

arrows. The authors concluded that arrow and gaze signals share common neural substrates, with potentially more efficient processing for arrow stimuli.

1.1.2 General domain or specific domain

So given the importance of the gaze, several studies have begun to explore the underlying attentional mechanisms, more specifically, the mechanisms of social attention (Chacon-Candia et al., 2023). Over the last two decades, there have been many studies about the question of social attention, (e.g., Frischen et al., 2007; Marotta et al., 2012; Risko et al., 2012). These studies have delved into various aspects of social attention, including the role of gaze direction, facial expressions, and social context in directing attention. For example, Marotta et al. (2012) investigated the impact of gaze direction on attentional orienting in social contexts, while Frischen et al. (2007) explored how facial expressions modulate attentional processes. Additionally, Risko et al. (2012) examined the influence of social cues on joint attention tasks.

Due to the importance of gaze in social contexts, some researchers have suggested that eye-gaze, when functioning as an attentional cue, might activate differential attentional orienting mechanisms when comparing to non-social cues, such as arrows (e.g., Friesen & Kingstone, 1998; Langton & Bruce, 1999).

Initially, researchers hypothesized that, given the lack of predictiveness of the gaze, the effect might be specific to the social nature of the cue (see, e.g., Friesen & Kingstone, 1998). Participants are typically faster at detecting or identifying a target when it appears at the gazed location, compared to the opposite, ungazed location (gaze cueing effect).

Contrary to this perspective, a substantial body of research has demonstrated behavioral evidence for similar effects when arrows are used as cues instead of eye gaze (Hommel et al., 2001; Kuhn & Benson, 2007; Tipples, 2002, 2008). For instance, participants respond more quickly to targets appearing in the direction indicated by an arrow (arrow cueing effect), even when the arrow is

counterpredictive and it would be advantageous for participants to redirect their attention away from the arrow-pointed position (Tipples, 2008).

There is still an important debate on this topic. Some findings suggest the existence of a shared mechanism between social and non-social stimuli (e.g., Posner, 1980), while others, conversely, propose two separate systems: a specific domain for social stimuli and a general domain for both social and non-social stimuli (e.g., Marotta et al., 2018; Marotta et al., 2019).

In particular, a large amount of research has directly examined the attentional orienting mechanism elicited by eye-gaze and arrow stimuli, employing several revisions of the traditional cueing paradigm (Posner, 1980). Some research indicates that both gaze and arrows produce the same cuing effect, suggesting a common underlying mechanism (Friesen & Kingstone, 1998; Langton & Bruce, 1999).

In this regard, there are previous studies that show no robust behavioral differences between eye-gaze and arrow cues. For instance, Galfano et al., (2012) aimed to shed light on the automaticity of attentional shifts triggered by gaze and arrows. The findings showed that both gaze and arrows trigger a reflexive shift of attention. Thus, it has been demonstrated that eye-gaze and arrows are capable of inducing very similar effects.

In the same vein, the research of Guzzon et al., (2010) probed if the central cues, such as eye-gaze or arrows, might induce reflexive-like attentional shift. In the first experiment they compared eye and arrow cues in a counter-predictive paradigm (i.e., participants are presented with cues that are intentionally incongruent with the subsequent target location), then in the second one they tested the time course of the attentional orienting triggered by eyes and arrows in a predictive paradigm. Finally, in the last experiment they evaluated the role of over-learned associations in cueing effects. In conclusion, the findings from this study demonstrated that both eye and arrow cues produce the same behavioral responses in spatial cueing tasks, even when employing a counter-predictive paradigm.

Similar effects of attentional orienting elicited by eye-gaze and arrow cues have also been observed from a psychophysiological perspective. Brignani et al. (2009), in their study, analyzed the event-related potentials (ERPs) associated with attentional shifts induced by arrows and eye-gaze, focusing on components such as P1, N1, P2a, P2p, and P3. These findings suggest that a fast and early attentional shift is subserved by the same neural mechanisms.

However, studies have typically investigated gaze and arrow cues based on their shared ability to convey directional information (Gibson & Kingstone, 2006). Hence, the possibility of different attentional mechanism for social and non-social stimuli has been ignored.

Marotta and colleagues (2012) conducted three separate experiments to investigate of different attentional orienting mechanisms under eye-gaze and arrow cueing. While one set of data replicated the previously mentioned results, demonstrating the existence of a same attentional mechanism for both social and non-social stimuli, the remaining data highlighted a qualitative dissociation in the type of attentional selection elicited by arrow and eye-gaze cues. These findings changed the idea that gaze and arrow cues involve similar attentional orienting mechanisms as proposed by previous studies (Ristic et al., 2002; Tipples, 2002). Instead, they provide evidence in favor of the idea that automatic orienting in response to gaze cues represents a unique attentional process that is qualitatively distinct from attentional orienting triggered by biologically irrelevant stimuli.

Cañadas & Lupiáñez (2012) investigated whether the social significance of gaze direction influenced spatial interference in response selection, using a variant of the spatial Stroop paradigm and three different stimuli: faces, isolated eyes, and symbolic eyes. This study consisted of three experiments, in each of these participants were required to perform a discrimination task in which they had to respond as fast and accurately as possible to the direction (left or right) of the stimuli displayed on the screen. These tasks produced two trial types, congruent trials (i.e., where face location and eye direction are the same) and incongruent

trials (i.e., where face location and eye direction are opposite). A different effect between social (faces and eyes) and non-social (symbolic eyes) stimuli has been found: in particular participants were faster in incongruent than congruent trials with social stimuli (RCE-reversed congruency effect) and the opposite effect was found with non-social stimuli (classical congruency effect with faster responses for congruent trials).

In conclusion, as previously mentioned, there are lines of thought concurring with the existence of a similar attention mechanism between non-social and social stimuli (i.e., general domain). However, other researchers argue for the existence of a unique attention mechanism, supported by the RCE, specifically for social stimuli, which qualitatively differs from the mechanism of non-social stimuli, i.e., specific domain (e.g., Cañadas & Lupiáñez, 2012; Marotta et al., 2018; Ricciardelli et al., 2013).

1.2 Spatial cueing paradigm

Many studies mentioned above are based on Posner's paradigm (Posner, 1980) or on a modification of it (e.g, Marotta et al., 2012). Posner's model of attentional orienting provides a framework for understanding how attention is directed in space. The "orienting" is a process of aligning attention with either a sensory input source or an internal semantic structure stored in memory. Several authors have proposed that the attentional function is carried out by three different attentional networks: alerting, executive and orienting (Posner & Boies 1971; Posner & Petersen 1990)

Posner introduced the spatial cueing paradigm, which was later revisited by Friesen and Kingstone (1998). Their study aimed to investigate whether shifts in gaze direction could influence attentional shifts in adult participants. They modified the traditional Posner cueing paradigm. Participants were instructed to maintain their gaze fixed on a face with eyes directed either right, left, or straight throughout the experiment. The gaze direction did not predict the location of the response stimulus. The results showed that response time (RT) was lower when a target appeared at the location where the eyes were looking (i.e., the cued location) compared to when it appeared at the opposite location (i.e., the uncued location).

Some researchers argue that the ability to shift attention in response to gaze direction plays a crucial role in the development of theory of mind (Baron-Cohen, 1995). However, an alternative perspective suggests that attentional shifts towards gaze direction might simply indicate an important cue to interesting aspects within the environment (Corkum & Moore, 1998).

In this regard, the metaanalysis conducted by Chacón-Candia and colleagues (2023) demonstrated that a nonpredictive shift in gaze, including schematic face, can trigger reflexive orienting. In this task there is a fixation point in the center of the screen followed by a schematic or real face looking straight ahead or with closed eyes (Figure 1 - A). Then participants see the same face looking on the

left or on the right from the fixation point. Subsequently target stimulus appears randomly either at the cued position (congruent trials) or at the opposite position indicated by the cue (incongruent trials). Afterwards, participants are tasked with detecting, localizing, or discriminating the target, typically through a key-press response. The findings showed that subjects were faster in congruent trials compared to incongruent trials, despite they have been informed that the central eye gaze does not predict where the target's localization. This orienting has been extensively found and studied in the literature (Friesen & Kingstone, 1998; Bonato et al., 2009; Ricciardelli et al., 2013).

Similarly, a cueing effect has been observed with arrows. Indeed, in the classical version of the cueing task (Posner, 1980), participants' behavioral responses to arrows closely resemble those elicited by eye-gaze stimuli (Figure 1 - B) (Chacón-Candia et al., 2023). Analysis of reaction times reveals no significant difference between responses to arrows and gaze stimuli, suggesting a comparable effect on attentional orienting.

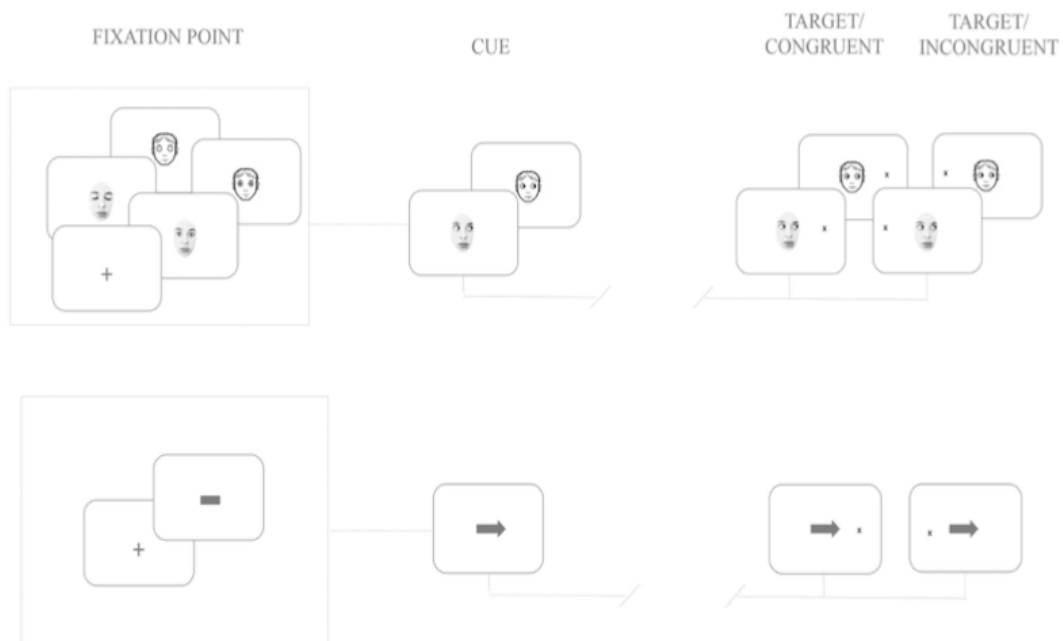


Fig. 1. Examples of a trial of the classic gaze (up) and arrow (down) cueing paradigms.

1.2.1 Object-Based and Space-Based Attention

A pioneering study of Egly, Driver, and Rafal (1994) was crucial in demonstrating that attentional selection operates not only for spatial locations but also for objects. They showed to participants two rectangles with a fixation point in the middle. Subsequently, targets appeared in one of three critical conditions: at the cued location, at the uncued location of the same rectangle (same-object target), or at the closest uncued location of the other rectangle (different-object target) as shown in Figure 2. The results demonstrate the space-based effect because participants were faster detecting validly cued targets than invalidly cued targets. Moreover, in the uncued target location condition, faster responses were found for same-object targets than for different-object targets. Therefore, they have established the existence of an object-based effect, demonstrating that the surrounding rectangle also influenced attention allocation.

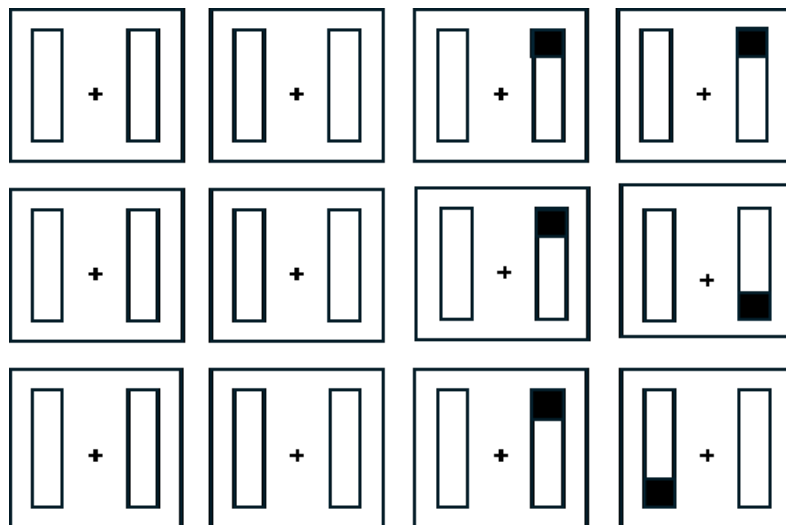


Fig. 2. The example of different conditions: valid, invalid in the same object and invalid in the different object in the experiment of Egly et al. (1994).

In this regard, Marotta et al. (2012) proposed a qualitative difference between biologically relevant (i.e., gaze) and irrelevant stimuli (i.e., arrows). Particularly, in their experiments they investigated whether object-based effects display in arrow cueing but not in eye-gaze cueing. For understanding this, they used variant of the object-cueing paradigm in which two rectangles were presented

with targets appearing at one end. The rectangles were titled, and the targets could appear either to the left or to the right of the fixation point (arrow or eye-gaze) in the same direction (and object) indicated by the cue (same-location/same-object trials) or in the opposite object and direction to which the cue was directed (opposite-location/opposite-object trials). In addition, the targets were either above or below fixation in the same object (same-object trials) to which attention was directed (but always in an orthogonal direction) or in the other object (different-object trials) as shown in the Figure 3.

The findings of Marotta and colleagues (2012) demonstrated the presence of attention spread across the entire object when the cue was a noninformative arrow, but not when it was a noninformative eye-gaze. Additionally, both types of stimuli (arrow and eye-gaze) elicited general cueing effects, as mentioned in other studies (e.g., Driver et al., 1999; Friesen & Kingstone, 1998). Indeed, for example, there was no qualitative difference observed during the same-location/same-object trial between arrow and eye-gaze.

On the contrary, object-based cueing effects were evidently influenced by the type of cue that was used to direct attention. Participants' responses, with arrows, were faster for the cued object than uncued object. This discovery suggests that arrow cues, functioning as exogenous cues, can spread the attention to the entire object in the visual field; in opposition, eye-gaze cues direct the attention towards to the cued location, not to the entire object.

Thus, these findings refute the hypothesis suggesting a shared attentional orienting mechanism between gaze and arrow cues. Instead, they suggest a qualitative difference between the attentional processes associated with gaze cues and those triggered by biologically irrelevant stimuli, such as arrows (Marotta et al., 2012).

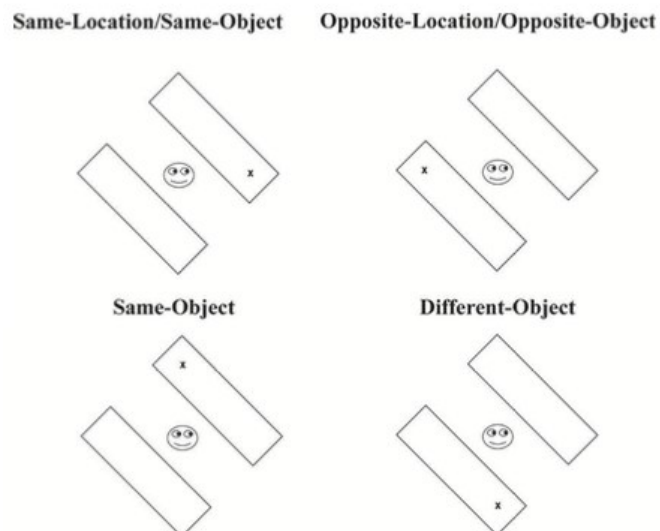


Fig. 3. The example represents a different conditions of the experiment of Marotta et al. (2012).

1.2.2 *Electrophysiological and behavioral evidence for a dissociation between eye-gaze and arrows attentional mechanisms*

The results of the aforementioned studies (e.g., Marotta et al., 2012; Marotta et al., 2018) only obtained indirect evidence of the processes contributing to the qualitative dissociation between eye-gaze and arrow attentional mechanisms.

On the contrary, Marotta and colleagues (2019) in their study employed techniques such as event-related potentials (ERPs). During the spatial interference task, they recorded electroencephalogram (EEG) data while participants responded to either eye-gaze or arrow stimuli. One reason why this study is important is that it demonstrates how arrows and gaze modulate both similar and different ERP components, leading to the conclusion that the two types of cues may share some underlying mechanisms, while also having distinct mechanisms responsible for their effects.

They measured different components, P1, N1, N170, N2, and P3 as markers of different stages of information processing. For example, the P1 and N1 components are commonly used as indices of early attentional allocation, enhancing perceptual processing and classification of stimuli (Vogel & Luck, 2000). Furthermore, the N170 is modulated by attention and is associated with

perceptual discrimination and categorization of stimuli, specially faces and eye stimuli. Moreover, the N2 component is involved in cognitive control defined as the monitoring or regulation of strategy (Folstein & Van Petten, 2008). Finally, the P3 reflects the subjective probability of the eliciting stimulus, indicating the controlled allocation of capacity-limited attentional resources towards relevant stimuli (Nieuwenhuis et al., 2005).

The study conducted by Marotta and colleagues (2019) aimed to assess the extent to which the anticipated critical behavioral dissociation between eye-gaze and arrows arises from early or later stages of neural processing. Specifically, if the variance in spatial conflict effects triggered by eye-gaze and arrows originates from early attentional and perceptual processing of the stimuli, a distinguishable congruency modulation should be evident in components such as P1, N1, and N170. Conversely, if the conflict dissociation between the two stimuli emerges from response generation and evaluative categorization of stimuli, a distinguishable congruency modulation should only manifest in later components such as N2 and P3.

In line with previous research (Marotta et al., 2018), behavioral data indicated that eye-gaze and arrows elicited opposing spatial interference effects: arrows resulted in faster response times (RTs) in congruent conditions, while eye-gaze showed faster responses in incongruent conditions. Anyway, the electrophysiological findings suggested the same congruency modulations for both stimulus types with the early components (P1, N1, and N170; Figure 4A), followed by later dissociations with the later components based on the stimulus type generating the conflict (N2 and P3; Figure 4B).

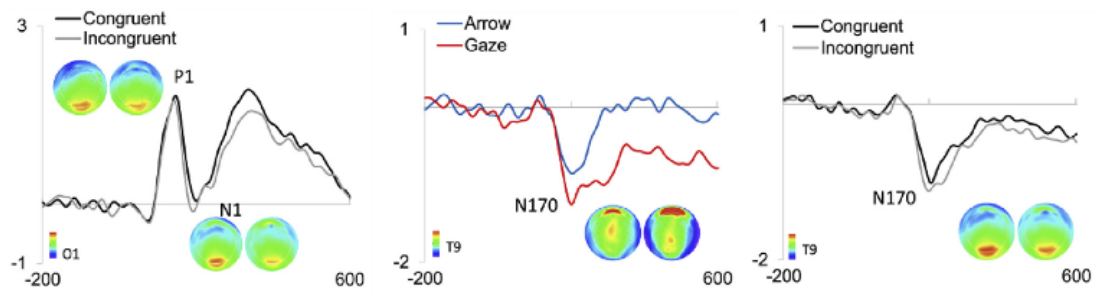


Fig. 4A. The same congruency modulations for both stimulus types (gaze and arrows) with the early components

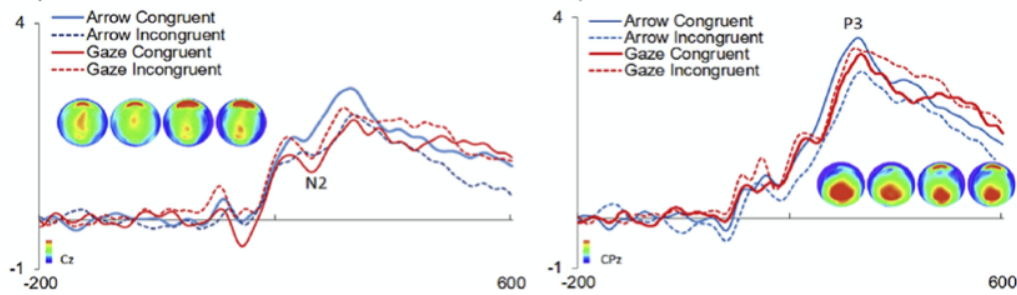


Fig. 4B. The dissociations between gaze and arrows with later components.

1.3 Reversed Spatial Stroop Effect

While some argue that eye gaze may represent a unique attentional stimulus due to its social significance, previous research has shown similar attentional effects for gaze and arrows when used as cues (e.g., Driver et al., 1999; Friesen & Kingstone, 1998; Santiesteban et al., 2014).

In this regard, as mentioned above, the attention to eye-gaze involves a special attentional process (Marotta et al., 2012; Marotta et al., 2018) distinguished from the attentional mechanisms engaged by symbolic directional stimuli such as arrows. Marotta and colleagues (2018), based on Cañadas & Lupiáñez (2012) observations, found an important difference between social and non-social stimuli. They used the spatial Stroop task (Lu & Proctor, 1995), in which participants were required to identify the direction of eyes or arrows (i.e., task-relevant information) presented to the left or the right of a fixation point, while ignoring the location of the stimuli (i.e., task-irrelevant information). This task produces two trial types, in congruent trials the direction indicated by the arrow/eye-gaze aligns with the spatial location (e.g., eyes looking at the left, presented on the left; Figure 5A), while in incongruent trials is the opposite (e.g., eyes looking at the left, presented on the right; Figure 5B). The results showed that arrows produced faster reaction times in congruent trials (i.e., a Standard Congruency Effect, SCE), whereas eye-gaze produced faster reaction times in incongruent trials (i.e., a Reversed Congruency Effect, RCE).

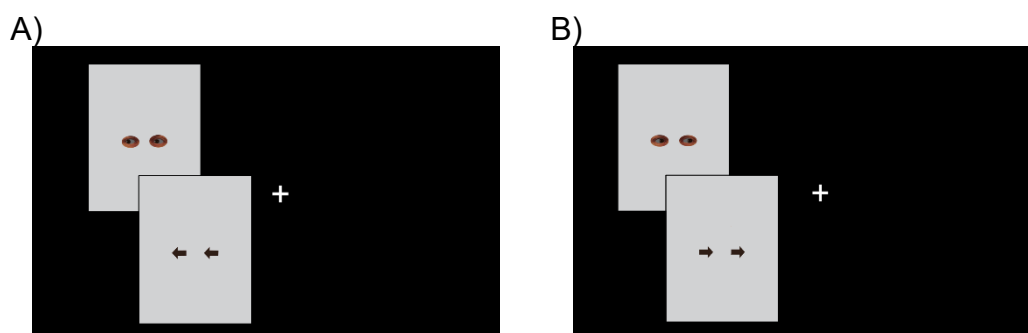


Fig. 5. Typical target used for the RCE effect observed for gaze targets. Congruent and incongruent conditions are represented respectively on the left and right panels.

The study offers evidence for the social importance of eye gaze and its distinct impact on attentional processing, highlighting its role in social cognition and interaction. These findings support the hypothesis of the existence of the domain-general attentional process shared by both gaze and arrow stimuli, while suggesting that separate brain circuits are specifically engaged by eye-gaze stimuli, particularly those associated with theory of mind and eye contact (Marotta et al., 2018).

This reversion has been interpreted as a consequence of the social significance of gaze processing (Cañadas & Lupiáñez, 2012; Dalmaso et al., 2023; Hemmerich et al., 2022; Marotta et al., 2018). Moreover, subsequent investigations have provided evidence supporting a shared attentional mechanism between social and non-social stimuli, as well as a distinct attentional mechanism, potentially related to social processing, for gaze stimuli that might trigger the reversion (Hemmerich et al., 2022; Marotta et al., 2019; Narganes-Pineda et al., 2023). According to these social accounts, the RCE phenomenon could be underlaid by eye-contact (Cañadas & Lupiáñez, 2021; Marotta et al., 2018), joint attention (Edwards et al., 2020), or joint distraction processes (Hemmerich et al., 2022), which would be strong enough and of opposite direction to the shared attentional mechanism, as to reverse the overall RCE observed with social targets.

Another possible explanation for the reversed congruency effect could be linked to the "mentalizing" theory (Baron-Cohen et al., 1997), which refers to the ability to infer another person's mental state from their eye gaze. Specifically, eye gaze may serve to perceive, interpret, and anticipate the behavior and/or intentions of others. In this context, instead of simply exchanging mutual gazes in the incongruent condition, both the participant and the stimulus might be involved in jointly encoding information about their own and others' attention. In other words, in incongruent trials, when eyes are presented on the left but looking to the right, they might be interpreted as signaling an intention to move to the right. Therefore, shifting attention to that location could be advantageous for the participant in terms of resource allocation (notably, right-looking eyes required a rightward

response). As a result, this could explain why gaze direction discrimination was faster in the incongruent condition.

Other studies have found that the reversed congruency effect is influenced by the emotional expression of a face when the entire face, rather than just the eyes, is used as the target (Jones, 2015; Torres-Marín et al., 2017), further supporting the social nature of the effect. The reversed congruency effect observed with eye-gaze stimuli seems consistent with the idea that participants respond faster when the target face appears to look directly at them. Specifically, it is important to note that when a gaze stimulus is presented on the left and looks to the right (i.e., an incongruent trial), it is actually looking toward the center, in the direction appropriate for making eye contact with the participant. In contrast, if the target face is presented on the left and looks to the left (congruent trial), it is looking away from the participant. This difference between direct and averted gaze may explain the reversal of the typical Stroop effect observed with eye gaze.

While additional research is needed to better understand the nature of the reverse congruence observed with gaze stimuli, both interpretations align with the notion that another person's gaze conveys more than directional information; it offers insight into their intentions and may signal approach or avoidance (Hietanen et al., 2008). Arrows simply provide directional information and do not convey intention or the possibility of social interaction. This is likely the reason why a classic spatial Stroop effect was observed when arrows were used as targets.

Hence, one of the aims of our study was to examine whether the reversed congruency effect (RCE) is due to the social nature of the stimulus.

CHAPTER 2 - UNDERLYING MECHANISMS OF ATTENTION

2.1 Automatic and controlled processes

Traditionally, the literature describes two types of attentional orienting: endogenous orienting, which involves the voluntary and internally driven direction of attention, and exogenous orienting, which involves the automatic shifting of attention triggered by the sudden appearance of a visual event in the periphery (Brignani et al., 2009).

Over the decades, experiments on spatial attention have utilized two different types of cues to influence attentional orientation: peripheral cues and central cues. The main difference between these lies in the type of attention they activate. Peripheral cues tend to trigger a reflexive and exogenous orientation of attention. In other words, attention is automatically drawn to the cue's location without the subject's voluntary control. In contrast, attentional orientation induced by central cues is more often endogenous and voluntary. The subject consciously decides to shift attention to the position indicated by the cue (Nakayama & Mackeben, 1989; Posner, 1980).

When it comes to exogenous attention, peripheral cues are utilized, such as a sudden flash of light or a brief sound that appears/resonates in a peripheral location, indicating one of the possible locations where the stimulus might subsequently appear (Narganes-Pineda et al., 2023). Peripheral cues directly indicate a specific location where attention automatically orientates. Central cues, like an arrow indicating a specific direction or a word indicating a place, need to be encoded to orient attention to the location indicated by the cue. For the attentional effect to occur, these types of cues need to be predictive, indicating the signaled (also called valid condition) location approximately 80% of the time (Jonides & Irwin, 1981).

2.1.1 Different brain activations

Corbetta and Shulman (2002) proposed two different networks of brain for these types of attentional orienting (endogenous and exogenous orienting).

One system, supported by the dorsal posterior parietal and frontal cortex, is responsible for the cognitive selection of sensory information and responses, governing goal-directed attention (endogenous mechanism). The other system, mainly lateralized to the right hemisphere and involving the temporoparietal and ventral frontal cortex, is activated during the detection of behaviorally relevant stimuli, especially when they are salient or unexpected, governing stimulus-driven attention (exogenous mechanism).

2.1.2 Social and non-social orienting in reflexive and voluntary processes

Hill and colleagues (2010) investigated two types of attentional orientation—social and non-social—in both automatic (reflexive) and controlled (voluntary) forms. Their findings showed that automatic attention to social stimuli is triggered by central cues such as faces and gaze direction. This reflexive social orientation begins early (approximately 100 ms) and persists longer compared to reflexive non-social orientation, which is elicited by stimuli like a brightened box (as shown in Hill et al., 2010).

Regarding controlled attention, they found that when gaze cues are used, responses to targets presented at a cued location are faster than when the gaze cues are non-predictive (e.g. Friesen et al., 2004). Interestingly, in non-social cueing experiments, results were similar to those observed in social cueing tasks, suggesting that a comparable mechanism of voluntary attentional shifting operates in response to predictive cues, whether social or non-social.

Additionally, Hill et al. (2010) highlighted that reflexive social and non-social orienting may share overlapping activation regions in the brain. However, neural responses to non-social cues appear to involve more widespread and bilateral brain regions.

An additional study investigating the mechanisms of visuospatial attention was conducted by Galfano and colleagues (2012). As mentioned earlier, it was initially thought that only peripheral cues could generate reflexive and automatic attention (Jonides & Irwin, 1981). In recent years, evidence has shown that arrows (i.e., central cues) can elicit a shift of attention even when they are uninformative about the target's location. This suggests that arrow-mediated orienting can be characterized as automatic (Tipples, 2002).

One of criteria to defining automatic attention shifts is resistance to suppression (Jonides & Irwin, 1981). Previous research has demonstrated that both gaze and arrow cues can induce attention shifts even when they are counterpredictive of the target's location.

Building upon these insights, the study of Galfano and colleagues (2012), aimed to further investigate the resistance to suppression of gaze and arrow mediated orienting. Participants known the target location with 100% certainty thanks to a directional word while gaze and arrow cues were irrelevant distractors. In this way they could understand whether these cues might involuntarily shift attention and interfere with the target detection task.

The findings showed that participants were faster in congruent trials than incongruent; they were faster to detect the target when the location indicated by the distractor and the upcoming target location were the same (i.e. congruent) than when they were different (i.e. incongruent). This clearly suggested that both arrows and gaze distractors triggered a reflexive shift of attention in the cued location. Hence, this research (Galfano et al., 2012) not only supports previous findings that eye gaze triggers automatic orienting of attention, but also highlights that arrows are able to induce a similar effect.

2.2 Conflict between relevant and irrelevant information

Related to the role of distractors in attention paradigms, it is important to explain the conflict between relevant and irrelevant information in conflict tasks.

When there is no compatibility between the stimulus and response (e.g., location and direction), a conflict emerges between relevant and irrelevant information, leading to slower and more error-prone responses.

2.2.1 *Simon Effect*

An example that illustrates this is the standard Simon task (Simon, 1990). In this task, participants are instructed to make spatially defined responses (e.g., pressing a left or right key) to non-spatial characteristics of a stimulus (e.g., auditory pitch or visual color) which appear randomly to their left or right. For instance, participants might be directed to press the right key upon hearing a high-pitched tone and the left key for a low-pitched tone. Although the spatial location of the stimulus (left or right) is irrelevant to the task, responses are generally faster when they align spatially with the stimulus that triggers them. This spatial Stimulus-Response (S-R) alignment enhances task performance, while non-corresponding S-R pairs tend to hinder it—a phenomenon known as the Simon effect (Dolk et al., 2014). It appears that individuals are unable to prevent the activation of spatially corresponding responses, highlighting the inherent limitations in human control over response activation (Hommel et al., 2004).

Based on the findings of Hommel (1993), it was observed that the Simon effect interacts with stimulus eccentricity, signal quality, and signal-background contrast. The relationship between the Simon effect and these factors can be explained by the temporal delay between irrelevant stimulus-response correspondence and factors that affect the early stages of information processing.

Essentially, the Simon effect is generally understood to result from a conflict between two internal codes: one corresponding to the task-relevant information of the stimulus, and the other linked to the irrelevant spatial location of the

stimulus. In other words, the temporal overlap hypothesis suggests that the magnitude of the Simon effect is strongly influenced by the temporal gap between the codes of the relevant and irrelevant stimulus dimensions.

Therefore, consistent with various studies (Hommel, 1994a; Rubichi et al., 1997; Valessi & Umiltà, 2009) when the temporal gap between the relevant and irrelevant dimensions is increased -either by delaying the relevant dimension or by precuing the irrelevant one- the Simon effect is reduced. This pattern of results suggests that the spatial code had time to dissipate before response selection occurred.

2.2.2 Flanker Effect

Another related phenomenon is the Flanker Effect, also known as the bilateral task paradigm, which was initially developed by Eriksen and Eriksen (1974). The task requires participants to reply to a target stimulus shown at fixation while ignoring other stimuli presented on either side of the target. This setup tests how effectively the target can be focused on and how well the distractors can be inhibited. The accuracy and speed of identifying the target depended on the similarity between the target and the noise elements (Eriksen & Eriksen, 1974). For example, in the Flanker paradigm experiment of Sanders and Lamers (2002), a subject is required to respond to a central target stimulus (such as a letter or an arrow) while ignoring surrounding stimuli (the "flankers") that can either be congruent, incongruent or neutral with the target. In the revision of Sanders and Lamers (2002) participants were required to press a left response key for target "A" and a right response key for target "B".

- Congruent condition: the distractors (flankers) are identical or consistent with the target stimulus. For example, letters from the target set that require the same response. (e.g. AAAAA).
- Incongruent condition: the distractors are different or in conflict with the target stimulus. For example, letters from the target set that require another response (e.g. BBABB).

- Neutral condition: the distractors are neither congruent nor incongruent with the target stimulus. For example, letters that do not belong to the target set (e.g. XXAXX).

The Flanker Effect is observed as slower reaction times (RT) and an increase in errors (decreased accuracy) in incongruent conditions compared to congruent conditions. This effect reflects the interference caused by incongruent distractors on the target stimuli selection process (Eriksen & Eriksen, 1974). These findings highlight the significant role that attentional mechanisms play in visual processing, showing that the ability to focus on relevant information can be compromised by irrelevant stimuli.

2.2.3 Stroop Effect

Another effect based on conflict between relevant and irrelevant information is the Stroop Effect. The Stroop effect is one of the most well-known phenomena in cognitive science and psychology. In its basic version, the task involves naming the color in which a word is printed while ignoring the meaning of the word itself. When the word is a color name that doesn't match the ink color it's printed in (for example, the word "GREEN" printed in red), this task becomes difficult, leading to slower and more error-prone responses (MacLeod, 2015). In this task there are two different conditions:

- Congruent condition: the ink color corresponds to the word's meaning. For example, the word "GREEN" is printed in green.
- Incongruent condition: the ink color doesn't match to the word's meaning. For example, the word "GREEN" is printed in red.

The difference in performance between the mismatched conditions, known as the incongruent condition, and the control condition is called the Stroop effect or Stroop interference.

The Stroop effect was first observed through vocal responses, which involve two distinct stages of language processing: perceiving the word stimulus and generating a vocal response (Figure 7).

It is well known that there are different brain regions responsible for these two processes. Based on the results of Okayasu et al. (2023) the Stroop Effect is linked with activity in the anterior cingulate, medial prefrontal, and bilateral prefrontal cortices.

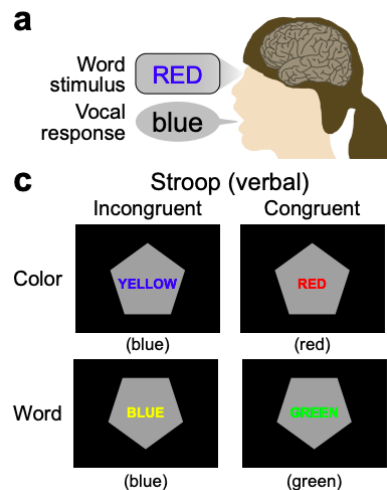


Figure 7. Stroop effect. It takes longer to name the color of a colored word when the word is colored in an inconsistent color (e.g., the word “RED” in blue-color font) (Okayasu et al., 2023).

The Stroop effect represents an excellent illustration of the conflict between endogenous and exogenous attention. To correctly name the color of the ink, participants must engage endogenous attention, which requires overriding the automatic process of reading and focusing instead on a more complex and less habitual task. On the other hand, the word itself acts as a distractor that automatically captures exogenous attention. This occurs because reading is an automated process causing the word to compete with the color for cognitive processing (Funes et al., 2007). Thus, the Stroop effect is an example of the conflict between top-down control (driven by endogenous attention to perform the task of naming the color) and bottom-up influence (the automatic activation of word reading).

2.2.4 *Dual-route model vs dual-stage model*

The dual-route models, in the context of relevant and irrelevant information, describes a theoretical framework proposing two parallel pathways for processing information. This model is often applied to cognitive tasks that involve conflicts between relevant and irrelevant stimuli, such as Simon or Flanker tasks (Ulrich et al., 2015). For instance, in the Simon tasks two different response processes are involved, the irrelevant spatial position triggers an automatic ipsilateral response through an unconditional route, while the relevant stimulus feature is processed according to task instructions and mapped to the correct response through a conditional route. Performance on corresponding trials is quicker and more accurate because the response is simultaneously activated by both the unconditional and conditional pathways. In contrast, non-corresponding trials are slower and less accurate because a conflict occurs between the automatically activated and the voluntarily translated response (De Jong et al., 1994). The dual-route models explain such conflict tasks as the Simon effect, where the irrelevant spatial response (e.g., the position of a stimulus) can influence performance, despite being unrelated to the task, due to the automatic processing of spatial information.

These dual-route models suggest that task-relevant information is regulated by controlled mechanisms, while irrelevant information is processed through more automatic and short-lived mechanism (Ponce et al., 2024).

In summary, dual-route models propose two parallel processing pathways (Koob et al., 2023).

- **Controlled process (for relevant information):** this route involves the processing of information relevant to the task. It is a slower, deliberate, and conscious process that requires attention and cognitive resources. For example, if the task requires responding to a specific piece of information (such as a high or low tone), the controlled process manages and accurately responds to the relevant stimulus.
- **Automatic process (for irrelevant information):** this route is associated with the processing of irrelevant information, which is not necessary for the task

but can still be processed automatically and quickly. This process is less controlled, often implicit, and occurs in parallel with the controlled route. For instance, the spatial position of a stimulus in a Simon task, which is not directly related to the required response, can still be processed automatically, influencing the response even though it is irrelevant to the task.

The dual-route process suggests that during cognitive tasks, relevant and irrelevant information are processed simultaneously but through separate mechanisms. The automatic route is fast and operates without conscious control, while the controlled route requires greater attention and cognitive resources to resolve the conflict between relevant and irrelevant information.

On the other hand, Tanaka et al. (2025) and Tanaka et al. (2024) proposed a dual-stage theory. The dual-stage model involves an approach in which cognitive processing occurs in two distinct phases. Typically, the first stage is more automatic and rapid, while the second stage is more controlled and deliberate. These two stages do not necessarily refer to relevant and irrelevant information but rather to the temporal sequence in which information is processed. The first stage may involve a quick processing of available information, while the second stage may involve a more careful and thoughtful evaluation of the same information. In the context of conflict between relevant and irrelevant stimuli (e.g., in the Simon task), a dual-stage model suggests that information is initially processed automatically (e.g., the position of the stimulus), with a controlled process being activated later to resolve the conflict and ensure an appropriate response.

Tanaka and colleagues (2024) interpreted this dual-stage theory in the context of target-background segregation and selective inhibition.

2.3 Stimuli Embedded Within a Background

Building on the several aforementioned insights, Román-Caballero and colleagues (2021a) conducted a study with the aim of testing in the same group of participants the findings of Cañadas and Lupiáñez (2012) and Marotta et al. (2018) of opposite behavioral effects for social and non-social targets. They used a whole face as a social stimulus and a set of two black arrows on a geometric mosaic as non-social stimulus. They aimed to replicate previous findings with similar stimulus complexity for both social and non-social stimuli, expecting to observe a standard congruency effect for arrows and a reversed spatial congruency effect for gaze.

However, the findings of experiment replicated the reversed congruency effect with gaze like in previous studies (Cañadas and Lupiáñez, 2012; Marotta et al., 2018) but, unexpectedly, arrows also produced a reversed congruency effect, although of smaller magnitude than gaze.

One possible explanation is the high perceptual complexity of the background required first segregating the target arrow from the background before determining its direction. Román-Caballero et al. (2021a) argued that complex target backgrounds required more time for target extraction compared to simpler ones (e.g., grey background; Marotta et al., 2018), thereby reducing the spatial Stroop effect. Consequently, the reversed congruency effect can be explained by the temporal dynamics of target segregation rather than the distinctive role of eye gaze in social communication; the longer the segregation process takes, the smaller the effect becomes.

Another explanation may be that the geometric background's patterns of colors and shapes activated an interpretation of these patterns as face-like stimuli. Based on this, in our experiment we tested this reversion using modified arrow stimuli that simulated faces.

Returning to the previous point Tanaka et al. (2024) examined whether non-gaze targets could elicit a reversed congruency effect when embedded in a complex background. To explore this, they conducted three different experiments, and they included the tongue as a target in the spatial Stroop task, alongside the traditional gaze and arrow target.

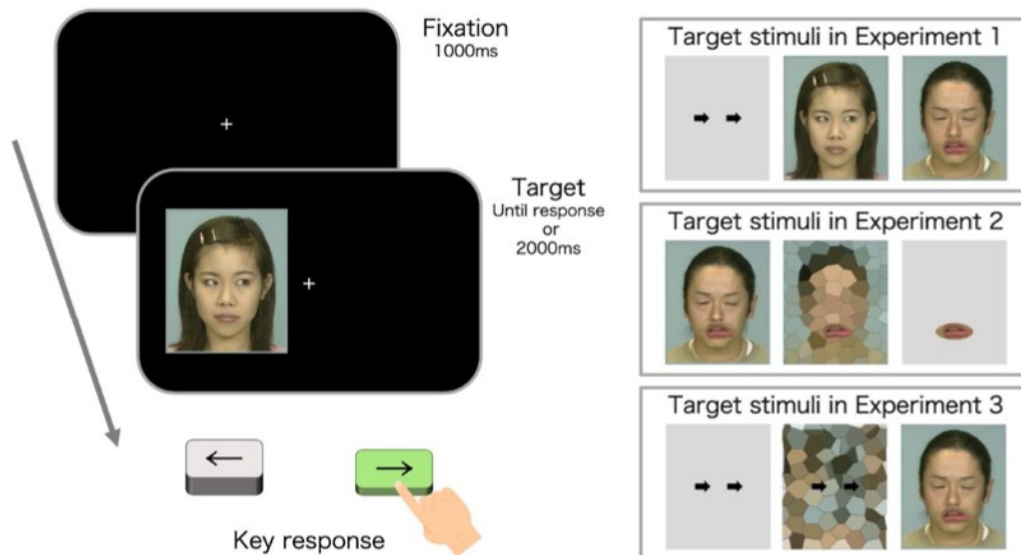


Figure 8. Stimulus presentation sequence illustrating an incongruent trial of gaze target (Tanaka et al., 2024)

If target–background segregation causes the reversed congruency effect, they expected the reversed congruency effect for both gaze and tongue targets because the facial background would impair the segregation of directional information. Conversely, if social processing mechanisms, such as eye contact and joint attention, are responsible (as suggested by previous studies: Cañadas & Lupiáñez, 2012; Hemmerich et al., 2022; Marotta et al., 2018) they would predict the reversed congruency effect only for gaze targets.

The findings of their three experiments showed that while the arrow target elicited the spatial Stroop effect, the gaze and tongue targets produced the reversed congruency effect. However, the spatial Stroop effect of arrows disappeared when arrow stimuli were embedded in the complex background. These results highlighted that the reversed effect is not a unique spatial interference elicited only when responding to gaze stimuli.

Based on this insight, they suggested a dual-stage account for the reversed congruency effect includes target-background segregation (Román-Caballero et al., 2021a, 2021b) and selective inhibition (Ridderinkhof et al., 2002).

The observation that reaction times were faster for "simple" stimuli (e.g., arrow) than for "complex" stimuli (e.g., arrow, tongue, and gaze) supports the hypothesis of a temporal delay. Indeed increased demands for target-background segregation delayed target extraction, resulting in a temporal gap between task-irrelevant coding (i.e., location) and task-relevant coding (i.e., direction, response). Román-Caballero et al. (2021a) hypothesised that this temporal gap attenuates the spatial Stroop effect by resolving location-based conflicts; the typical spatial Stroop effect appears on arrow targets on a simple background and disappears on a complex background.

Moreover, they propose that the initial phase of segregating the target from the background that is necessary for gaze is followed by a second phase of active suppression of the location, ultimately leading to the reversion. The activation-suppression hypothesis was proposed, suggesting that direct activation triggered by irrelevant stimulus features is selectively inhibited, and this selective inhibition requires some time to develop (Ridderinkhof, 2002a). Tanaka and colleagues (2024) adopted this inhibition theory for the spatial Stroop task. In this case, the target's location is irrelevant to the task, and therefore the corresponding spatial representation (e.g., "left" if the target appears on the left side) is inhibited. If the target's direction is congruent with this inhibited representation, additional time is required to reactivate it and respond. As a result, responses are slower in congruent trials where the spatial code aligns with the directional code (e.g., a "left" target appearing on the left) compared to incongruent trials (e.g., a "left" target appearing on the right), leading to the reversed congruency effect.

This process is slow and controlled (rather than automatic) that occurs only after the target has been distinguished from the background. This could explain the spatial Stroop effect observed with both social stimuli (such as gaze or gestures) and non-social stimuli (such as arrows).

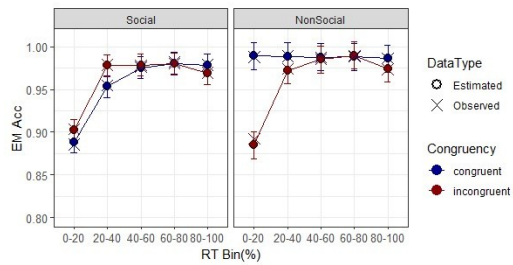
2.4 Conditional Accuracy Function (CAF)

Following these observations, our laboratory performed a reanalysis of several studies using a distributional approach (Ponce et al., 2024). In conflict tasks, a distributional approach facilitates the analysis of how experimental manipulations affect the conflict effect at various stages of cognitive processing (Balota & Abrams, 1995; De Jong et al., 1994). This method allows for the exploration of the interaction between relevant and irrelevant information, based on a common theoretical model that posits two parallel processing pathways (Ridderinkhof, 2002; Ulrich et al., 2015). In dual-route models, the initial amplification of irrelevant spatial information by the automatic mechanism, increases the probability of selecting incorrect responses in incongruent trials. However, as reaction times become longer, the influence of the automatic mechanism diminishes, allowing the controlled route to improve performance, therefore, increasing the probability of selecting the correct response.

Opposite patterns related to the congruency effect were observed within the fastest responses for social and non-social stimuli using the Conditional Accuracy Function tool (CAF). This tool has been used to analyze the temporal dynamics of conflict tasks (Heitz, 2014), and represents the variations of accuracy across the reaction time (RT) distribution.

The usual pattern was observed for the fastest responses of non-social stimuli, with lower accuracy rate for incongruent than congruent trials, whereas for the slowest responses high accuracy was observed for both congruency levels, as typically observed. Interestingly, the CAFs observed for social stimuli showed a quite different pattern. First, for the fastest responses, lower accuracy was observed for both congruent and incongruent trials as compared to the slowest responses. Second, lower accuracy was observed for congruent than incongruent trials within the fastest responses for social targets (Ponce et al., 2024) (Figure 9).

A)



B)

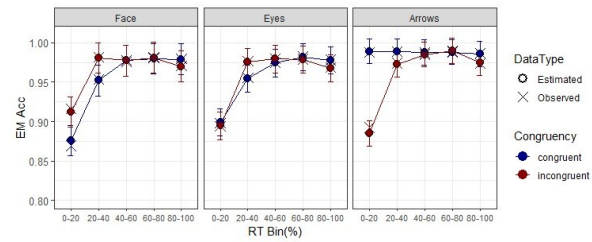


Figure 9. CAFs from models A (A) and (B) in Ponce et al. (2024, figures 1 & 2) study. The former compared social (i.e., eye-gaze and faces) vs. non-social (i.e., arrows) stimuli. Model B, compared face vs. eye-gaze vs. arrows stimuli. The y-axis represents the estimated marginal means of accuracy rate (EM Acc). The bars represent the 95% confidence intervals of the EM Acc.

Considering these findings, examining how accuracy varies over reaction time depending on the type of stimuli used can be crucial for gaining insight into the dissociation observed between social and non-social attention. Moreover, despite electrophysiological evidence suggesting that some differences occur at later stages, this dissociation appears during processing (Marotta et al., 2019), it is conceivable that earlier stages might influence this dissociation. This is particularly relevant considering evidence that faces can be distinguished from other stimuli during early processing stages (e.g., Bentin et al., 1996; Nemrodov et al., 2014). Therefore, the use of a distributional approach (Balota & Abrams, 1995; De Jong et al., 1994), employing tools such as the Conditional Accuracy Function (CAF) could shed light on when the congruency effects start to diverge between social and non-social stimuli.

CHAPTER 3 - THE RESEARCH

3.1 Experiment 1

Building on previous results (e.g. Cañadas & Lupiáñez, 2012; Marotta et al., 2018) we know that there is an important difference between social and non-social stimuli. Marotta and collaborators (2018) adapted the spatial interference paradigm to investigate differences between stimuli using pairs of arrows and eyes, aiming to equalize the physical characteristics of the stimuli. These stimuli were presented in separate blocks. The results replicated findings from Cañadas and Lupiáñez (2012), showing a standard congruency effect with the arrows (faster responses on congruent trials compared to incongruent ones) and a reversed congruency effect with the eyes (faster responses on incongruent than congruent trials) (Figure 10).

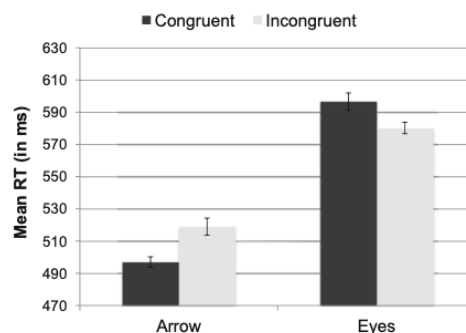


Figure 10. Mean reaction times for each target type and trial type condition (Marotta et al., 2018).

Considering several findings (e.g. Bonventre & Marotta et al., 2023; Hemmerich et al., 2022; Narganes-Pineda et al., 2023), examining how accuracy varies with reaction time based on the type of stimuli used can be essential for understanding the dissociation observed between social and non-social attention.

Indeed, even though not always statistically significant, a dissociation in congruency effects between arrows and gaze has been also noted when analyzing error rates. Ponce and colleagues (2024) employed a distributional approach using tools such as the Conditional Accuracy Function (CAF) to identify

differences in congruency effects between social and non-social stimuli as a function of speed of responses. Indeed, the CAF links task execution time to accuracy providing insights into how response accuracy changes in relation to reaction time (Heitz, 2014; Van Maanen et al., 2019). Using the CAF tool, Ponce et al. (2024) found the opposite patterns of congruency within the fastest responses for social and non-social stimuli (see Figure 8). When non-social stimuli were used, accuracy was high throughout the distribution under congruent conditions. However, under incongruent conditions, accuracy was lower for the fastest reaction times (RTs) and improved as RTs increased. Furthermore interestingly, the CAFs observed for social stimuli showed a quite different pattern. First, for the fastest responses, lower accuracy was observed for both congruent and incongruent trials as compared to the slowest responses. Second, even lower accuracy was observed for congruent than incongruent trials within the fastest responses for social targets.

The standard congruency effect observed for non-social stimuli has been easily explained as due to the automatic response (i.e., to then location) being emitted on fast responses before control can inhibit them. However, the reversed congruency observed for accuracy in fast responses to gaze is difficult to explain, as it is not clear which automatic tendency would lead to press in fastest responses to congruent gaze, the key opposite to the location and direction of the gaze. Furthermore, it is important to note that if the reversion were caused by a second inhibitory phase, as proposed by Tanaka et al. (2024), it would likely occur and be observed during the slower rather than the fastest responses.

In any case, the lower accuracy for fast responses to both incongruent and congruent gaze targets must be due to the automatic activation of irrelevant responses. One possibility is that these automatic responses are associated with the irrelevant location of the entire target in incongruent trials, as with non-social stimuli; interestingly, the relative position of the more salient part of the target (i.e., the sclera) compared to the less salient part (i.e., the pupil) on congruent trials (Figure 11) might lead to further activation of the opposite response on congruent gaze trials.

For instance, also the findings of Chen et al. (2022) showed that stimuli with equivalent perceptual characteristics displayed SCE, regardless of whether they were social or non-social. This suggests that congruence effects, whether triggered by social or non-social stimuli, might primarily be driven by their perceptual properties. So, based on this intuition as well, the higher saliency of the sclera compared to the pupil, which is on the opposite side to the correct response on congruent trials, could explain the automatic activation of incorrect responses in fastest responses to congruent gaze trials. If participants responses were influenced by the saliency of the sclera, the accuracy rate would decrease, showing the pattern described earlier in the fastest responses during congruent trials.

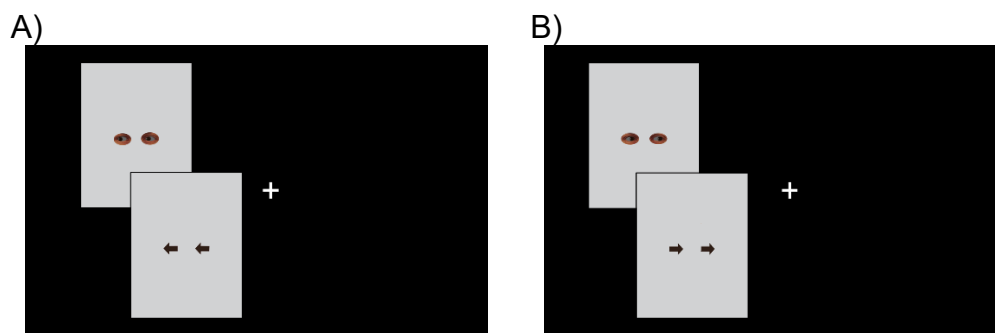


Figure 11. Typical target used for the RCE effect observed for gaze targets. Congruent and incongruent conditions are represented respectively on the left and right panels.

The aim of the present study was to test the hypothesis that the reversed congruency observed in the CAF with gaze is caused by the incongruent location of the salient sclera (opposite to the less salient eyes). If that hypothesis is correct, we should replicate the patterns observed with CAFs adapting the non-social stimuli to have a pattern of contrast similar to eye-gaze.

To make this possible, we will use two types of arrow targets. The first group, called “Eye-gaze version”, resembles the contrast between pupil and sclera (i.e. darker, i.e., less salient, on the target arrowhead) while the second group, called “Anti-eye-gaze version”, has the opposite pattern (i.e. darker, i.e., less salient on the non-target arrow tail; see Figure 12).

3.1.1 Hypothesis

If the reversion is influenced by the contrasting characteristics between the pupil and the sclera, we expect to observe the RCE with arrows in the “eye-gaze version,” characterized by slower responses in congruent trials compared to incongruent ones. Additionally, we anticipate a potentially larger SCE in the “anti-eye-gaze version,” with faster responses in congruent than in incongruent trials. Furthermore, with the “eye-gaze version” stimuli, we expect to replicate the patterns previously identified by our lab in CAFs, mirroring findings with social stimuli. Thus, on faster responses it is expected a reduction of the accuracy rates for both congruency levels, with further reduced accuracy rates for congruent than incongruent trials. On the other hand, with the “anti-eye-gaze version”, we expect to find the usual pattern observed for arrows, i.e., poor performance within the fastest responses to incongruent, but not to congruent trials, and good performance for both congruent and incongruent trials on the slowest reaction times.

3.1.2 Method

Participants

A sample of 36 adults, with a mean age of 21,7 years, participated in the experiment. All of them were students from the University of Granada who signed an informed consent form and receive partial course credit for their participation. Participants were naïve as to the purpose of the experiment. The study was conducted following the ethical guidelines laid down by the ethical committee of the University of Granada (3232/CEIH/2023 approval of the research project), in accordance with the ethical standards of the 1964 Declaration of Helsinki.

Power analyses were conducted using the dataset from Marotta et al. (2018), employing different analytic methods (see R script in <https://osf.io/3fdwk>). We evaluated the power of a sample size (N = 36) to detect the interaction between target type and congruency on a single-trial basis. For this, we utilized the lme4

package (Bates et al., 2015) to build a linear mixed-effects model and the *simr* package (Green & MacLeod, 2016) for conducting power analyses, achieving a power of .96 for the interaction. Furthermore, we applied the same method, but narrowed our analysis to only the congruency effect of eye-gaze targets with the same sample size ($N = 36$), achieving a power of .82.

In addition, using the *pwr* R package (Champlery et al., 2022), with $N = 36$ and an alpha of .05, we aimed to detect an effect size of $d_z = .49$, as estimated from the congruency effect with eye-gaze in the study by Marotta et al. (2018). This analysis yielded a power of .81 in a two-sided paired t-test. Lastly, employing the *Superpower* R package (Lakens & Caldwell et al., 2021) with the same sample size for a Cohen's f of 1.08, we obtained a power of .99 for the interaction between target type and congruency.

Stimuli and procedure

As mentioned above, there were two types of targets according to their contrast direction: in the “eye-gaze version” the arrows were similar to the contrast between the pupil and the sclera, i.e., with the more salient part opposite to the target arrow head, while in “anti-eye-gaze version”, were opposite.

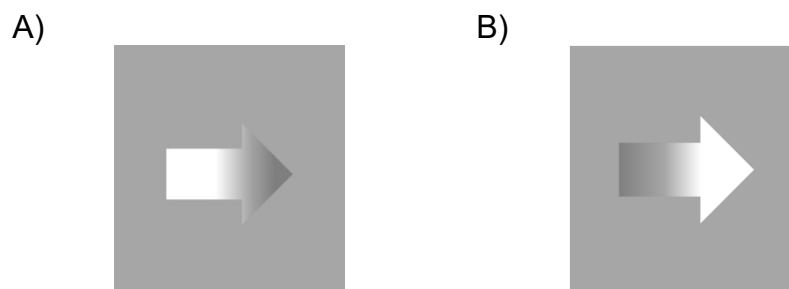


Figure 12: Examples of the arrow stimuli in condition “eye-gaze version” (A) and condition “anti-eye-gaze version” (B)

The experiment procedure was based on Marotta et al. (2018) study. It was composed of two blocks with a pause between blocks, and preceded by 15 practice trials only before the first block. The condition of eye-gaze version was randomly presented within the same block, each of them having 64 trials.

Participants performed the spatial Stroop task, requiring them to respond as fast and accurately as possible to the direction (left or right) indicated by the arrows.

Each trial began with a white fixation cross presented in the center of the screen for 1000ms (Figure 13). Then the arrows pointing to the right or to the left was presented to either the left or the right of the fixation cross for 2000ms. Participants were instructed to fixate the cross, and to press the “C” key in response to targets indicating the left and the “M” key in response to targets indicating the right, independent of the target’s location.

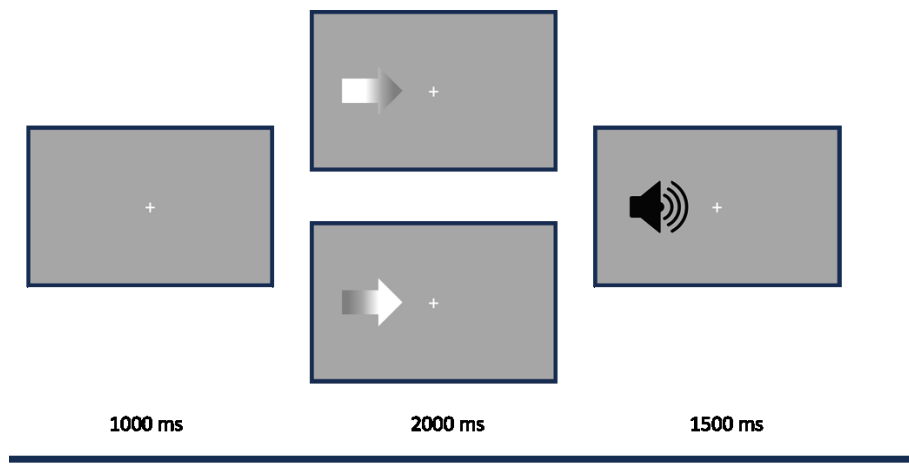


Figure 13: Schematic view of a trial sequence in Experiment 1. The example represents incongruent trials: “eye-gaze version” (upper) and “anti-eye-gaze version” (down). The speaker icon represents the auditory feedback.

Design and statistical analyses

The experiment had a (2 x 2) two-factor repeated measure design: target version (eye-gaze vs. anti-eye-gaze), and congruency (congruent vs incongruent trials). We used parametric analyses of variance and post-hoc contrast methods, adhering to the assumptions where they apply; if they do not, we recurred to non-parametric methods. Post-hoc contrasts were performed, specifically focusing on contrasts between congruency levels within each target version condition, for both dependent variables, reaction times and accuracy rates.

For CAFs analyses, reaction times were sorted from fastest to slowest before dividing the distribution into five 20% bins (e.g., Hübner & Töbel, 2019). Accuracy rates were calculated for each participant within each condition (i.e, target version, congruency, and Bin). This will result in a three-factor repeated measures design (2 x 2 x 5): target version (eye-gaze vs. anti-eye-gaze),

congruency (congruent vs. incongruent trials), and Bin (5 levels). In addition, we performed several Bonferroni post-hoc analyses for comparisons between Bins by congruency levels, and between congruent and incongruent trials across the entire distribution.

3.1.3 Results

Reaction Time

The ANOVA performed on mean RTs showed a main effect of Congruency $F_{(1,35)} = 84.372$, $p < 0.001$, $\eta_p^2 = 0.707$, with slower RTs for the incongruent trials compared to congruent trials (455.23ms vs. 487.28ms; see Figure 13). The main effect of Target Type was marginally significant ($p = 0.058$). Importantly, the critical Target Type \times Congruency interaction was significant, $F_{(1,35)} = 5.394$, $p < 0.026$, $\eta_p^2 = 0.134$.

Post-hoc tests on each target type showed that RTs were significantly slower on incongruent than on congruent trials when both AntiLike, $t(35) = -9.117$, $p < 0.001$, $d = -0.577$, and EyesLike, $t(35) = -6.795$, $p < 0.001$, $d = -0.430$, stimuli were used as targets. The interaction revealed that although no RCE was observed for any condition, a 37 ms congruency effect was observed for AntiLike stimuli, whereas it was reduced to 27 for the EyesLike condition (see Table 1).

Descriptive Statistics				
	AntiLike congruent	AntiLike incongruent	EyesLike congruent	EyesLike incongruent
Mean	450.817	487.590	459.668	487.017
Std. Deviation	58.288	69.120	57.286	69.217

Table 1. Mean correct reaction times (RTs, in milliseconds) and standard deviations (SDs) of each condition (Target Type and Congruency).

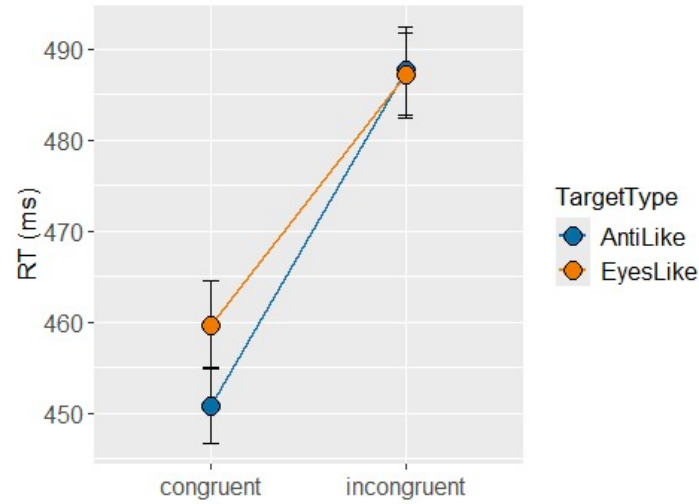


Figure 13. This plot shows slower RTs in incongruent than congruent trials with both type of stimuli.

In addition, we performed paired t-test in function of the Stroop Effect between both Target Type, $t(35) = 2.322$, $p = 0.026$, $d = 0.387$. We found that AntiLike has shown 36.77ms whereas EyesLike has shown 27.41ms (see Table 2).

Descriptive Statistics		
	StroopEffect AntiLike	StroopEffect EyesLike
Mean	36.773	27.410
Std. Deviation	23.357	25.018

Table 2. Mean and standard deviations (SDs) of Stroop Effect.

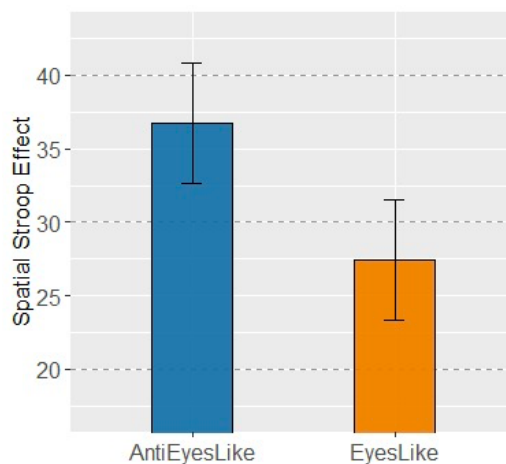


Figure 14. Stroop Effect by Target Type condition; the figure shows the higher Stroop effect for the AntiEyesLike condition.

Accuracy

The analysis of errors showed that the main effect of Congruency, $F_{(1,35)} = 10.81$, $p = 0.002$, $\eta_p^2 = 0.236$, was significant, with high accuracy in congruent trials than incongruent ones (0.98 vs 0.95; see Table 3). While the main effect of Target Type was not significant ($p = 0.794$).

However, of relevance for the present study, the Target Type \times Congruency interaction was not significant, $F_{(1, 35)} = 1.657$, $p = 0.206$, $\eta_p^2 = 0.045$.

Descriptive Statistics				
	AntiEyesLike congruent	AntiEyesLike incongruent	EyesLike congruent_10	EyesLike incongruent_11
Mean	0.986	0.950	0.980	0.953
Std. Deviation	0.024	0.068	0.025	0.072

Table 3. Mean of errors (accuracy) and standard deviations (SDs) of each condition (Target Type and Congruency).

CAF

The ANOVA revealed no main effect of Target Type, $F_{(1,35)} = 0.190$, $p = 0.665$, $\eta_p^2 = 0.005$. However, there was a significant main effect of Congruency, $F_{(1,35)} = 10.924$, $p = 0.002$, $\eta_p^2 = 0.238$; and Bin, $F_{(1,35)} = 16.953$, $p < 0.001$, $\eta_p^2 = 0.326$. The interaction between Bin and Congruency, $F_{(1,35)} = 26.889$, $p < 0.001$, $\eta_p^2 = 0.434$, was also significant. However, and critical to our hypothesis, the three way interaction was clearly not significant.

These results suggest that the CAF showed the standard behavior of non-social stimuli; participants showed a higher and a stable accuracy in congruent trials throughout the distribution. In contrast, in incongruent trials participants were less accurate within the fastest reaction time. More specific with AntiLike participants showed more errors in incongruent than congruent trials in Bin 1, $t(35) = 5.329$, $p < 0.001$, $d = 0.888$, and in Bin 2 $t(35) = 3.718$, $p < 0.001$, $d = 0.620$. There was also a marginal significance in Bin 3, $t(35) = 1.994$, $p = 0.054$, $d = 0.332$.

Moreover, with EyesLike participants showed more errors in incongruent than congruent trials in Bin 1, $t(35) = 4.565$, $p < 0.001$, $d = 0.761$; the differences in errors in the other bins were not significant (as shown in Figure 15).

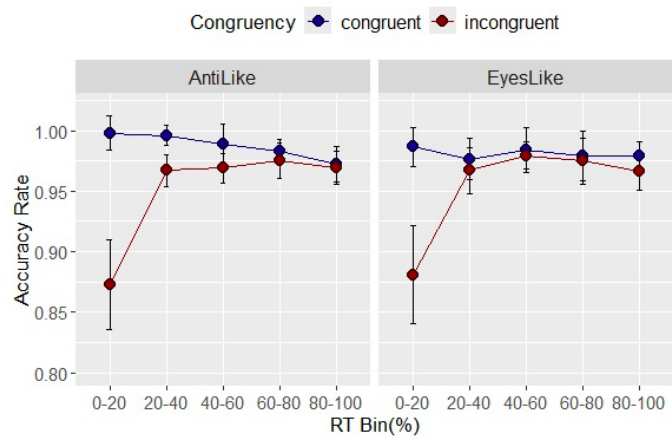


Figure 15. CAF by Target Type by Congruency, by bin.

3.2 Experiment 2

Experiment 1 aimed to explore whether the dissociations observed in reaction times and CAFs with gaze are due to the incongruent location of the salient sclera as opposed to the less salient pupils. To accomplish this, we adapted non-social stimuli to have a similar contrast pattern to that of eye-gaze. We used two types of arrow targets: EyesLike arrows (darker, less salient on the target arrowhead) and AntiEyesLike arrows (darker, less salient on the arrow tail). The results revealed no reversion for either type of target, consistently showing the SCE independently of the contrasting features. Additionally, no dissociation was observed in the CAF; both EyesLike and AntiEyesLike arrows showed similar patterns, consistent with non-social stimuli in distributional analysis studies. This suggests that the asymmetrical contrast features did not influence the reversion.

However, based on Tanaka et al. (2024)'s account, the reversion might be facilitated due to an active inhibition stage of the task-irrelevant information. They propose that the initial phase of segregating the directional information from the background necessary for gaze processing (as described in Román-Caballero et al. 2021a; 2021b) is followed by a second phase of active suppression of the spatial code, thereby resolving conflict (Ridderinkhof, 2002). Specifically, in the congruent condition, where the spatial code aligns with the directional code, selective inhibition mechanisms suppress the correct spatial code, delaying the response. Conversely, in the incongruent condition, selective inhibition suppresses the incorrect spatial code for the location, speeding up the correct response. These task-related dynamics ultimately lead to the reversion observed in reaction times.

However, as stated above, the CAF analysis showed the dissociation between gaze and arrows in the fastest, not the slowest responses. Therefore, we thought that our original hypothesis that the reversed congruency observed for gaze is due to the incongruent location of the salient sclera in relation to the less salient

pupils might be correct, but only, when it is necessary to segregate the eyes from the background.

To further examine this dynamic and test this specific hypothesis, a second experiment is proposed. We replicated the first one using the same procedure and stimuli. Additionally, we added a second experimental block using the same two target types embedded in a mosaic background, similar to those used in Román-Caballero et al (2021a) but adapted in color and design.

3.2.1 Hypothesis

The principal aim is to test whether the contrasting features act after the second stage, when the task-irrelevant information processing (i.e., location code) has already been suppressed. Moreover, to analyze the temporal dynamics, we employed a distributional approach alongside mean reaction time and accuracy rate analyses.

Background-block condition

If the reversion is facilitated by the contrasting characteristic between the pupil and the sclera after the active suppression to segregate the relevant (eyes) from the task-irrelevant (background) information, it is expected to observe the RCE with arrows in the EyesLike condition, characterized by slower responses in congruent than incongruent trials. Additionally, we anticipate a reduction of the SCE compared to experiment 1, produced by the temporal gap with the AntiEyesLike target type.

Based on Tanaka et al. (2024)'s proposal, we expect to observe the reversion with EyesLike target type within the medium and slowest reaction times, resulting in significant reversion in delta plots for the medium and slowest quantiles. Regarding CAF analysis, following the findings of experiment 1, we hypothesize that the contrast effect of the target types did not facilitate a dissociation. Therefore, we expect higher error rates within the fastest, and maybe medium, responses in incongruent trials, due to the necessity of processing the irrelevant

information first (i.e., location code), which will be hindered by the backgrounds. If the need to segregate activate the inhibitory mechanism related to incongruency of the sclera-pupils saliency, then we expect also reduced accuracy for congruent fastest responses.

Non-background block condition

In this condition, we expect to replicate the results observed in Experiment 1. We anticipate observing the standard congruency effect for both target types in the mean reaction time analysis. Additionally, we predict no dissociation in CAF analyses. Moreover, we expect to observe patterns similar to those seen with non-social stimuli in distributional analysis in both delta plots (i.e., a reduction of the conflict effect across the distribution) and CAFs (i.e., lower accuracy rate in incongruent trials only within the fastest responses).

3.2.2 Method

Participants

A sample of 40 adults, with a mean age of 22,5 years, participated in the experiment. The same power analyses as in Experiment 1 were used. However, we increased the sample size to 40 to account for potential measurement error due to online data collection.

All participants were students from the University of Granada, who signed an informed consent form and receive either a payment (6 euros) or credit course for their participation. Participants were naïve to the purpose of the experiment. The study was conducted following the ethical guidelines laid down by the University of Granada (3232/CEIH/2023 approval of the research project), in accordance with the ethical standards of the 1964 Declaration of Helsinki.

Stimuli and procedure

The study was conducted online. The task was programmed using OpenSesame (Mathot et al., 2022) and administered via JATOS (Lange et al., 2015). The standard block stimuli were the same as in Experiment 1, while the stimuli for the

background block were the two target types embedded in a complex background, as displayed in Figure 16. There were two background types, with one being a mirrored version of the other.

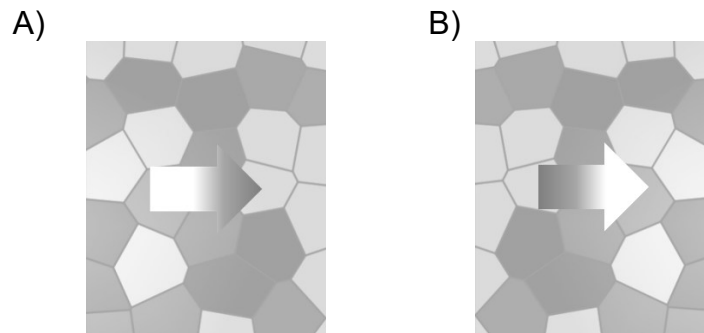


Figure 16. Examples of the target type stimuli in condition EyesLike (A) and condition AntiEyesLike (B).

The experimental procedure was based on the study by Marotta et al. (2018). It consisted of two main blocks, one with background and the other without background, with order counterbalanced across participants. Each block was preceded by 10 practice trials and included two sub-blocks, each containing 128 trials with a brief pause in between, totaling 256 trials per block. Participants performed the spatial Stroop task, requiring them to respond as fast and accurately as possible to the direction (left or right) indicated by the arrows. Each trial began with a white fixation cross presented in the center of the screen for 1000 ms (Figure 17). Then the arrows pointing to the right or to the left were presented to either the left or the right of the fixation cross for 2000ms. Participants were instructed to fixate the cross and were instructed to press the “C” key in response to targets indicating the left and the “M” key in response to targets indicating the right, independent of the target’s location.

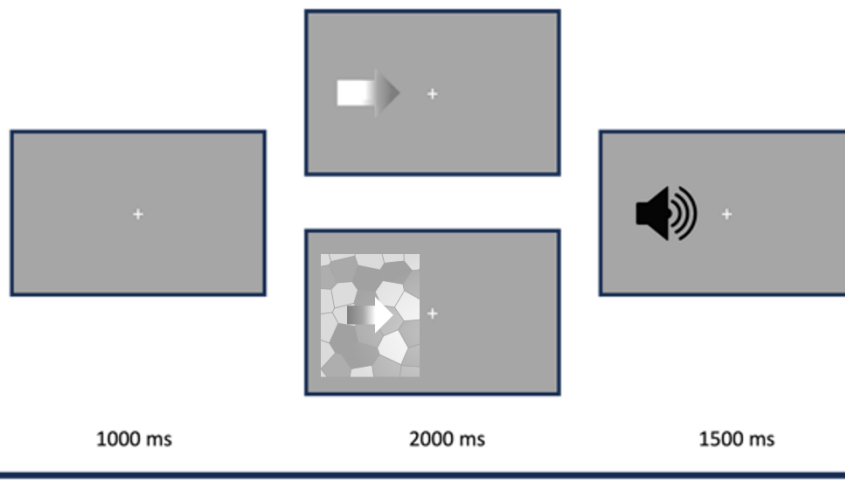


Figure 17: Schematic view of a trial sequence in Experiment 2. The example represents incongruent trials: non-background & EyesLike version (upper) and background AntiEyesLike version” (down). The speaker icon represents the auditory feedback.

Design and statistical analyses

The experiment had a three-factor repeated measures design (2 x 2 x 2): block type (background vs. non-background), target type (EyesLike vs. AntiEyesLike), and congruency (congruent vs incongruent). As in Marotta et al. (2018), we excluded trials slower than 1300 ms and faster than 200 ms for both mean analyses and distributional analyses. Additionally, participants with 3 SD of the mean error rates were considered as outliers. Analyses of variance were used to test the interactions. Moreover, as we are interested in the congruency effects, we performed several planned contrasts regarding the congruency condition (i.e., paired two-sided t-tests) by each background and target type conditions, for both dependent variables, reaction times and accuracy rates.

Delta functions were obtained using quantile averaging (Ratcliff, 1979) on correct responses by participant, by each condition. We used the quantile function in R, with the type 8 quantile estimator, as recommended by Hyndman & Fan (1996). The probabilities used to obtain 5 quantile points were: .17, .33, .5, .67, & .83. The delta function for each condition was determined by subtracting the quantile reaction times (RTs) for congruent trials from those for incongruent trials and then associating the results with the corresponding mean quantile RTs. This resulted

in a two-factor repeated measures design (2 x 5) by each background condition which was analyzed separately: Target Type (EyesLike vs. AntiEyesLike) and quantile (5 levels). To test for the spatial interference effect size across the distribution, one sample t-tests against zero was conducted within each quantile.

For CAFs analyses, the background conditions were analyzed separately as well. Reaction times were sorted from fastest to slowest before dividing the distribution into five 20% bins (e.g., Hübner & Töbel, 2019). Accuracy rates were calculated for each participant within each condition (i.e, target version, congruency, and Bin). This resulted in a three-factor repeated measures design (2 x 2 x 5): target version (eye-gaze vs. anti-eye-gaze), congruency (congruent vs. incongruent trials), and Bin (5 levels). In addition, we performed several contrast analyses to perform the comparisons between Bins by congruency levels, and between congruent and incongruent trials across the entire distribution.

3.2.3 Results

Reaction Time

The ANOVA performed on mean RTs showed a significant main effect of Congruency, $F_{(1,39)} = 42.758$, $p < 0.001$, $\eta_p^2 = 0.523$, with a slower RTs for the incongruent trials than the congruent ones (500.99ms vs 459.31ms; see Table 4). The main effect of Target Type was significant, $F_{(1,39)} = 60.938$, $p < 0.001$, $\eta_p^2 = 0.610$, with faster RTs when AntiLike stimuli were used as targets compared to EyesLike stimuli (474.75ms vs 484.19ms). Also the main effect of Background was significant, $F_{(1,39)} = 275.796$, $p < 0.001$, $\eta_p^2 = 0.876$, with a slower RTs in background conditions compared to standard ones.

However, the critical Target Type × Congruency × Background interaction was not significant, $F_{(1,39)} = 0.152$, $p = 0.699$, $\eta_p^2 = 0.004$.

Descriptive Statistics

	RT_Backg_AntiEyesLike_congruent	RT_Backg_AntiEyesLike_incongruent	RT_Backg_EyesLike_congruent	RT_Backg_EyesLike_incongruent
Mean	603.453	614.352	636.731	647.632
Std. Deviation	81.963	90.818	71.630	72.541

	RT_Std_AntiEyesLike_congruent	RT_Std_AntiEyesLike_incongruent	RT_Std_EyesLike_congruent	RT_Std_EyesLike_incongruent
Mean	451.954	498.866	466.809	503.719
Std. Deviation	78.735	89.096	87.521	90.818

Table 4. Mean correct reaction times (RTs, in milliseconds) and standard deviations (SDs) of each condition (Target Type and Congruency) with and without background.

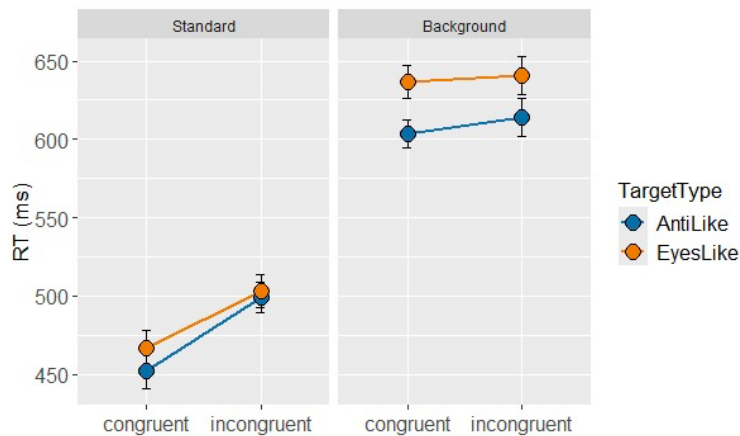


Figure 18. This plot shows the RTs of congruent and incongruent trials for both type of target in two different conditions (Standard vs Background).

Despite the three-way interaction was not significant, as preregistered, we performed several paired-t tests by block (Standard vs. Background) to investigate if the congruency effect was produced. The paired t-tests showed faster RTs with congruent than incongruent trials when no background was used with both AntiLike, $t(39) = -9.583$, $p < 0.001$, $d = -1.515$, and EyesLike, $t(39) = -6.100$, $p < 0.001$, $d = -0.965$, replicating the results of the experiment 1. Conversely, when the targets were embedded in a complex background, only AntiLike targets showed faster RT with congruent than incongruent trials, $t(39) = 2.203$, $p = 0.034$, $d = -0.384$, although, the effect size is small.

In addition, we found a reduced Stroop Effect when the targets were embedded in a mosaic background, respectively 10.90ms and 4.20ms, with AntiLike and EyesLike targets when compared with targets in no-background conditions, 46.91ms and 36.29ms with AntiLike and EyesLike stimuli (see Table 5 and Figure 19).

Descriptive Statistics

	Effect_Backg_AntiEyesLike	Effect_Std_AntiEyesLike	Effect_Backg_EyesLike	Effect_S
Mean	10.899	46.912	4.199	
Std. Deviation	31.288	30.961	36.323	

Table 5. Mean and standard deviations (SDs) of Stroop Effect.

These differences were significant performing paired t-test in function of the Stroop Effect between Standard and Background conditions with AntiLike stimuli, $t(39) = -7.080$, $p < 0.001$, $d = -1.119$, and also with EyesLike stimuli, $t(39) = -3.854$, $p < 0.001$, $d = -0.609$.

In addition, we didn't find any differences when comparing between Target Types of the same block ($p > 0.05$).

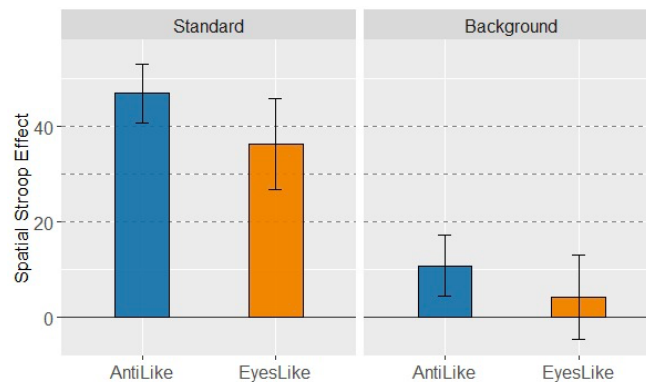


Figure 19. The figure shows higher Stroop Effect for Standard condition compared to Background ones.

Accuracy

The analysis of errors showed that the main effect of Congruency, $F_{(1,39)} = 19.643$, $p < 0.001$, $\eta^2_p = 0.335$, was significant, with high accuracy in congruent trials than incongruent ones (0.97 vs 0.93; see Table 6) as observed in Experiment 1. Also, the main effect of Target Type was significant, $F_{(1,39)} = 13.898$, $p < 0.001$, $\eta^2_p = 0.263$ with less errors when AntiLike stimuli used as targets compared to EyesLike stimuli (0.96 vs 0.94). In contrast, the main effect of Background was not significant ($p = 0.130$).

Moreover, also the Target Type \times Congruency \times Background interaction was not significant ($p = 0.331$).

Descriptive Statistics				
	Acc_Backg_AntiEyesLike_congruent	Acc_Backg_AntiEyesLike_incongruent	Acc_Backg_EyesLike_congruent	Acc_Backg_EyesLike_incongruent
Mean	0.970	0.951	0.940	0.908
Std. Deviation	0.045	0.052	0.054	0.119
	Acc_Std_AntiEyesLike_congruent	Acc_Std_AntiEyesLike_incongruent	Acc_Std_EyesLike_congruent	Acc_Std_EyesLike_incongruent
Mean	0.982	0.933	0.973	0.930
Std. Deviation	0.023	0.075	0.036	0.070

Table 6. Mean of errors (accuracy) and standard deviations (SDs) of each condition (Target Type and Congruency) with and without background.

CAF

The ANOVA showed the main effect of Target Type, $F_{(1,39)} = 11.438$, $p = 0.002$, $n_p^2 = 0.227$; Congruency, $F_{(1,39)} = 19.809$, $p < 0.001$, $n_p^2 = 0.337$; and Bin, $F_{(1,39)} = 80.320$, $p < 0.001$, $n_p^2 = 0.673$.

The critical Background x Target Type, Background x Congruency, Background x Bin, Congruency x Bin, Background x Target Type x Bin and Background x Congruency x Bin interactions were significant ($p < 0.05$). In contrast, the other interactions and the main effect of Background, $F_{(1,39)} = 2.755$, $p = 0.105$, $n_p^2 = 0.066$, were not significant.

For CAF's analysis we replicated the results of Experiment 1 for the conditions without background. More specific we found that with both type of stimuli in Bin 1 participants showed more errors in incongruent than congruent trials, $t(39) = 6.207$, $p < 0.001$, $d = 0.981$ – Anti Like stimuli and $t(39) = 5.097$, $p < 0.001$, $d = 0.806$ – EyesLike stimuli. Meanwhile we found a significant effect in the same direction in Bin 2 for EyesLike stimuli, $t(39) = 2.948$, $p = 0.005$, $d = 0.466$.

Regarding background-block conditions, we found a marginal difference only with AntiLike stimuli in Bin 1, $t(39) = 2.037$, $p = 0.048$, $d = 0.322$, although, the effect size is small. For the other background conditions, we didn't find a significant differences in both type of stimuli for accuracy.

In addition, with EyesLike targets the errors increased in congruent trials with background than in congruent trials without background, $t(39) = 5.063$, $p < 0.001$, $d = 0.801$ (as shown in Figure 20).

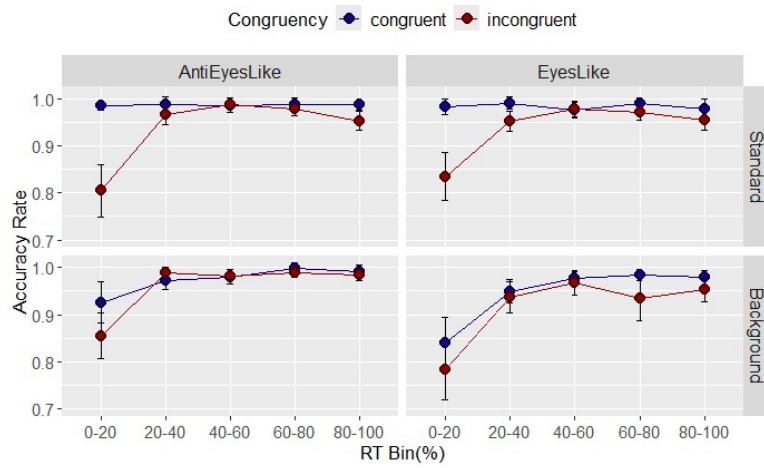


Figure 20. CAF by Target Type by Congruency in two different conditions (Background and Standard), by bin.

CHAPTER 4 – DISCUSSION

4.1 General Aspects, Aims and general hypotheses

The ability to process others' gaze is crucial for survival. On one hand, gaze holds significant social value, as it facilitates the initiation of interactions with others. On the other hand, it serves as a powerful attentional cue, guiding our focus toward the location where another person is directing their attention (Birmingham & Kingstone, 2009). This tendency to orient one's attention where others are looking is known as Social Attention. Social attention and its implications have been discussed in the literature since the 1970s. More recently, advancements in technology have led to a significant expansion of social attention research over the past 20 years (e.g., Birmingham & Kingstone, 2009; Kingstone, 2009; Salley & Colombo, 2016).

Social attention is the cognitive process that allows individuals to detect, prioritize, and respond to socially relevant cues, such as eye gaze, facial expressions, gestures, and body language. It plays a crucial role in communication, joint attention, and understanding others' intentions, emotions, and mental states (Baron-Cohen et al., 1997; Carpenter & Tomasello, 1995).

Due to its importance in social contexts, some researchers have suggested that eye-gaze, when functioning as an attentional cue, might activate differential attentional orienting mechanisms compared to other non-social cues, such as arrows (e.g., Friesen & Kingstone, 1998; Langton & Bruce, 1999; Marotta et al., 2018, 2019). As a result, eye gaze has been used as a stimulus to facilitate attentional orienting in space in different paradigms such as the Posner paradigm, where eye gaze serves as a cue (e.g., Chacón-Candia et al., 2022; Friesen & Kingston, 1998; Marotta et al., 2012), and the Spatial Interference paradigm (Lu & Proctor, 1995), where eye gaze functions as a target (e.g., Aranda-Martin et al., 2022; Hemmerich et al., 2022; Marotta et al., 2018; Narganes-Pineda et al., 2023).

The present study, which employed the Spatial Interference paradigm, was designed to extend previous findings on the dissociation between social and non-social stimuli. Using a social version of the Spatial Stroop task (Marotta et al., 2018), various laboratories have reported a reversed effect when eye gaze is used as target (e.g., Cañadas & Lupiáñez, 2012; Dalmaso et al., 2023; Ishikawa et al., 2022; Jones, 2015; Tanaka et al., 2023; Torres-Martín et al., 2017), characterized by faster responses in incongruent trials than in congruent ones—a phenomenon known as the reversed congruency effect (RCE), as it is opposite to the standard congruency effect observed with non-social stimuli like arrows (i.e., faster responses for congruent than incongruent trials).

Moreover, by analyzing the temporal dynamics via the conditional accuracy function (CAF), it was observed that the RCE is produced also in terms of accuracy (Ponce et al., 2024), showing specific patterns within the fastest responses. Participants, did not only show a reduced accuracy for both congruency levels, but also showed even higher error rates in congruent than incongruent trials, suggesting that early processing stages might affect the reversion when social targets are employed.

Some researchers view the reversion as a consequence of the social significance of gaze (Cañadas & Lupiáñez, 2012; Dalmaso et al., 2023; Marotta et al., 2018). For instance, Edwards et al. (2020) attribute the RCE to mechanisms of joint attention, highlighting how individuals naturally align their focus with others. Still, others suggest a connection to joint distraction, proposing that gaze cues might direct attention outside the task in congruent trials (e.g., a right looking face presented to the right) leading to slower reaction times (Hemmerich et al., 2022).

Finally, some researchers proposed the eye-contact hypothesis highlighting that the mediation of eye contact could explain the RCE (Cañadas & Lupiáñez, 2012; Marotta et al., 2018). Participants are usually fast to identify a direct gaze or a gaze that appears to be looking at them (Chen & Yeh, 2012; Conty et al., 2007; Senju & Johnson, 2009), which is the case for incongruent gaze trials. In gaze congruent trials, the gaze is averted from the participant, and this might be perceived as avoidance.

On the other hand, non-social theories emphasize the temporal dynamics of the task (Tanaka et al., 2024). Chen and colleagues (2022) proposed that stimulus perceptual features might lead to the reversion after observing the SCE with perceptual similar stimuli. They proposed that the reversion would be a phenomenon linked to the modulation of the attentional focus, an account based on the zoom-lens model (Ericksen & James, 1986). In this line, Tanaka et al. (2024) proposed a dual-stage hypothesis. Based on Román-Caballero et al. (2021a, 2021b) findings, it was observed that when stimuli are embedded in a complex background, the segregation process creates a temporal gap (see Hommel, 1993). Tanaka et al. (2024) suggested that the initial segregation of gaze from the background is followed by the active suppression of location (Ridderinkhof, 2002), ultimately leading to the observed reversion.

Among social and non-social accounts, it has been proposed different studies. However, this is the first study proposing an experimental manipulation in function of the specific features of gaze, which could be relevant throughout the information processing, affecting mainly the fastest responses.

In this regard, the human sclera (the white area surrounding the darker iris) is more exposed than in other species, and it has a distinctive morphology that we are predisposed to recognize and discriminate from an early age (Kobayashi & Kohshima, 1997). As mentioned above, the gaze of others influences how we interact with the environment, an effect that does not occur with non-social cues like arrows (Bayliss et al., 2006). Moreover, gaze can act as a strong distractor amplifying spatial interference when it is included peripherally in a spatial Stroop Task. We hypothesized that the salient sclera might trigger fast responses to its relative location within the eyes, which is opposite to the requested responses to the gaze (i.e., pupil) direction. This would explain the observed less accurate fast responses, and the slowest correct responses for congruent trials.

To test this hypothesis, we used the Spatial Stroop paradigm in two experiments, in which we manipulated the stimuli to simulate the contrast between the pupil and the sclera. In each experiment we used only non-social targets, i.e., arrows,

and we manipulated the contrast of either the tail or the head of the arrow. If the reversion is influenced by the contrasting features between the pupil and the sclera, we expected to observe the RCE with arrows (i.e., a stimulus that do not elicit a social component) that simulate gaze (darker, i.e., less salient, on the target arrowhead) with faster responses in incongruent trials compared to congruent ones.

In the second experiment, with the same stimuli inserted within a background, we expected the reversion to occur after the active suppression needed to segregate the relevant information (eyes) from the task-irrelevant information (background). Additionally, we analyzed accuracy via CAF to identify differences in congruency effects between social and non-social stimuli, particularly to determine whether the RCE for accuracy could be replicated, in case the reversion is facilitated by the contrasting sclera vs. pupil features.

4.2 Discussion of each experiment

4.2.1 Experiment 1

In Experiment 1, we used two different types of arrows, one designed to simulate the contrast between the pupil and sclera (EyesLike stimuli), with the more salient part of the arrow being opposite to the target arrowhead. We expected to observe the reversion with EyesLike stimuli and the standard congruency effect with AntiLike stimuli (where the the more salient part of the arrow was the target arrowhead. However, we did not find the reversion for EyesLike. Instead, a similar pattern of results was observed for both EyesLike and AntiLike targets, with faster RTs in congruent trials compared to incongruent ones. This suggests that both target types act similarly to the standard arrows used by previous research (e.g., Marotta et al. 2018)

In addition, we also found that RTs for AntiLike stimuli were faster than those for EyesLike stimuli in congruent trials. This suggest that AntiLike targets facilitate task-relevant processing, particularly in congruent trials).

In any case, the results do not support a perceptual elicitation of the RCE in function of the contrasting features of the stimuli. Thus, the reversion might be elicited by a social component (e.g., Aranda-Martín et al., 2023; Hemmerich et al., 2022; Marotta et al., 2018).

The other important finding was a larger stroop effect for the AntiLike condition. This phenomenon could be explained in terms of perceptual contrast. One possible explanation is a higher level of interference between irrelevant information (position) and relevant information (direction) in tasks where the AntiLike stimuli were used as targets. Under these conditions, irrelevant information may be more salient.

Viviani and colleagues (2023) discussed about Stroop asymmetry between relevant and irrelevant information. The prevalent explanation for this phenomenon is the automaticity account, according to which this occurs because the two dimensions imply different amounts of processing effort. Consequently,

the more automatized process (position) interferes with the less automatic one (direction).

Another possible explanation is weaker Stroop effect with EyesLike stimuli, driven by a facilitation effect that improves the processing of relevant information. This facilitation may result from the segregation process, which introduces a temporal gap, allowing task-irrelevant information to decay more efficiently and consequently reducing the spatial interference effect.

Indeed, strong evidence from conflict paradigms (e.g., Stroop and Simon tasks) supports the notion that the activation generated by a distracting dimension of the target decays over time. In this regard, Hommel (1993) proposed the temporal-delay hypothesis, suggesting that an increase in the temporal distance between the formation of irrelevant and relevant stimulus codes would lead to a reduced interference effect.

For instance, Dyer (1971) and Glaser and Glaser (1982) presented in a classic color-naming Stroop task the irrelevant word in black before displaying the same word in color. The results showed a decrease in the Stroop effect as a function of the temporal lag between the onset of both dimensions.

A similar pattern has been observed in Simon and spatial Stroop tasks where a cue was used to pre-expose the irrelevant target position (Hommel, 1993; Martín-Arévalo et al., 2020), as well as in flanker paradigms where distracting information preceded the target (Botella et al., 2002). It is likely that by the time the relevant information appears, the activation triggered by the distracting dimension has weakened, leading to a reduction in conflict.

Although we cannot determine whether the Stroop effect results from higher interference or a facilitation effect, further research is needed on this topic.

Moreover, we observed a higher number of errors in incongruent trials compared to congruent ones, which appears to support the notion that incongruent conditions involve a greater level of interference between conflicting information (e.g., when a stimulus is presented on the left but indicates the right). This once again confirms the absence of dissociation between AntiLike and EyesLike stimuli, as they exhibit a pattern similar to standard arrows in Marotta et al. (2018).

In addition, in congruent trials, direction and position align, allowing participants to respond more quickly and accurately due to the absence of conflict. Their responses are largely automatic, requiring minimal cognitive control. Conversely, in incongruent trials the automatic response does not match the correct one, thus increasing participants' errors.

Finally, the results of the CAF analysis revealed no general dissociation. Participants exhibited higher accuracy in congruent trials across the entire response distribution for both target types. In contrast, during incongruent trials, participants showed more errors in the fastest responses, but demonstrated similar patterns of behavior for both target types in slower and median response times, consistent with congruent trials. The automatic response capture is also reflected in the CAF, where accuracy is lower for fast responses, as these are the most automatic (Ridderinkhof, 2002).

This result stands in contrast to our hypothesis, which anticipated replicating the gaze effects identified by Ponce et al. (2024) for EyesLike stimuli—specifically, improved performance in incongruent trials compared to congruent trials within the fastest responses.

To sum up, EyesLike and AntiLike stimuli showed a typical behavior of non-social stimuli. This result suggests that information regarding the contrast the pupil and the sclera do not facilitate reversion and supports the idea that might be a social component behind the processing of gaze.

4.2.2 Experiment 2

In Experiment 2, we implemented two different block conditions using the same stimuli as in the first experiment: one with a background (i.e., background condition) and one without background (i.e., standard condition).

We expected to replicate the results observed in previous experiment in the standard condition while, in background condition, we predicted to observe the RCE with arrows in the EyesLike condition, characterized by slower responses in congruent than incongruent trials.

The hypothesis for the standard condition was confirmed. In contrast, there was no reversion either when the stimuli were embedded in a background, although results showed again faster RTs when AntiLike stimuli were used as targets compared to EyesLike stimuli in each congruency condition. Once again, this demonstrates that the reversion is not influenced by perceptual contrast, further supporting social theories.

Moreover, we found faster responses in the standard conditions compared to the background ones. Slower response times in the background condition might be attributed to the high perceptual complexity of the background, which may have necessitated the segregation of the target arrow from the background before discriminating its direction. The increased perceptual complexity introduced based on the study by Román-Caballero and colleagues (2021a, 2021b), would make it necessary to first perceptually segregate the target from the background. This process may delay the selection of the arrow target, allowing the conflicting spatial dimension to decay before the relevant code is fully established.

However, when the targets were embedded in a complex background, only AntiLike targets showed faster RT with congruent than incongruent trials. In general, when a background was present, no differences should be observed between congruent and incongruent trials because the Stroop effect is reduced (Román-Caballero et al., 2021a, 2021b). In planned contrast, the Stroop effect persisted for the AntiLike stimuli, highlighting the fact that this target type elicits a stronger effect, as observed in standard conditions. Regardless, a general

reduction in the interference effect was found in background conditions compared to standard conditions.

Regarding accuracy, participants showed more errors in incongruent trials compared to congruent ones, both in background conditions and in standard conditions. Therefore, we did not observe any effect related to the presence of the complex background in terms of accuracy.

Finally, concerning CAF's analysis, we replicated the results of Experiment 1 for the conditions without background with less accuracy in incongruent trials than congruent ones in particular within fastest responses (Bin 1) for both types of stimuli. Hence, the accuracy pattern was replicated in line with what is observed in the literature. For instance, Ponce and colleagues (2024) observed that incongruent trials exhibited lower accuracy rates in the first Bin compared to subsequent Bins when non-social targets were used. This pattern can be explained by temporal dynamics mechanisms. In the first Bin, the automatic mechanism's initial boost (Ülrich et al., 2015) amplifies the influence of irrelevant information, increasing the probability to select the incorrect response in incongruent trials. However, from the second bin onward, as the impact of irrelevant information diminishes - either due to decay (Hommel, 1993) or active suppression (Ridderinkhof, 2002a, 2002b) - accuracy rates improve showing no differences between congruent and incongruent trials.

As mentioned above, in background conditions, the Stroop effect is reduced. Indeed, we also observed that the difference of errors decreases, and it seems that both congruent and incongruent trials facilitate similar accuracy across entire distribution with a slightly reduce within fastest responses.

4.3 General Discussion and conclusions

Research regarding social attention explores how spatial attention is allocated to different types of stimuli. These experiments aimed to examine the allocation of attention to social and non-social stimuli, with a particular focus on whether this difference is driven by the social significance of the stimulus or by the perceptual contrast between the pupil and the sclera. To investigate this, a spatial interference task was employed, and non-social stimuli were manipulated to simulate a perceptual contrast. Additionally, a background was introduced to more precisely examine whether temporal dynamics influence this type of attentional orientation.

We used a spatial Stroop task that explores the interference/facilitation produced by irrelevant spatial information. As in the classical version, the design of this task produced congruent (e.g, right-pointing stimuli presented on the right) and incongruent (e.g., right-pointing stimuli presented on the left) trials.

In the first experiment of this thesis, a similar pattern of behavior was observed for both EyesLike and AntiLike targets in terms of reaction times and accuracy. Thus, it seems that the reversal is not influenced by perceptual contrast features, particularly by the contrast between the pupil and sclera.

Given the above, there remains the possibility of a significant social component, as supported by social theories (i.e. Aranda-Martín et al., 2022; Hemmerich et al., 2022; Ishikawa et al., 2021; Jones, 2015; Marotta et al., 2018, 2019; Torres-Marín et al., 2017) and by all related concepts, such as joint attention (Edwards et al., 2020), joint distraction (Hemmerich et al., 2022), and eye contact hypothesis (Cañadas & Lupiáñez, 2012; Marotta et al., 2018).

Even in the second experiment, no reversion was observed. This suggests that, despite the stimulus being embedded within a background, the latter influence participants' performance, but without reversing the congruency effect. These results are consistent with a previous study by Román-Caballero and colleagues (2021a) about these conditions of increased perceptual complexity that would make it necessary to first perceptually segregate the target from the background.

This would delay the selection process of the arrow target. As a result, by the time the relevant code (i.e., target direction) is formed, the conflicting spatial dimension will have diminished. However, the fact that there is no reversed congruency effect for EyesLike arrows even with the background might favor a social explanation for the reversed congruency effect, although there is not yet a clear explanation the observed CAF effect with eyes.

Nevertheless, the thesis is not without limitations. Firstly, the stimuli used one type of contrast. It will be important to test the observed patterns with different contrasting methods, darker vs. lighter, and/or contrasting colors. In the future, a similar study could be conducted by incorporating a preliminary baseline experiment to compare the behavior of a eye-gaze with that of the EyesLike stimulus we employed. This approach would allow a more precise assessment of whether the effects observed with the two stimuli are genuinely comparable. Alternatively, the eye-gaze stimulus could be directly incorporated into the experiment, allowing for a direct comparison of its effects. This approach would enable an objective, confirmation that the manipulation of EyesLike stimulus effectively works as a gaze simulator. In the absence of such validation, the study remains constrained by the subjective selection of stimuli.

However, the arrows are more informative stimuli for conveying directional information in this type of task. Despite arrows and gaze facilitate attentional orienting, Friesen et al. (2004) proposed a different shift of attention. Gaze-triggered attention is considered highly reflexive due to the presence of a neural architecture specialized for processing eyes. This effect is involuntary and difficult to suppress, reflecting the social importance of gaze in human communication. But arrows also serve as directional cues and, most importantly, are well-learned stimuli, which may grant them a more salient indicative power. Their effectiveness in guiding attention likely stems from extensive exposure and reinforcement in everyday contexts, making them highly recognizable and easily processed. This characteristic may have attenuated the differences, regarding the contrast used, across conditions in our study. Given their strong learned association with

directionality, arrows could have facilitated attentional shifts in a way that changing the contrast between experimental conditions did not elicit overall differential patterns.

Another limitation of the stimuli used in our study may also relate to their shape. Specifically, the arrowhead may serve as a more salient directional cue compared to a more rounded shape (i.e. oval), potentially enhancing its effectiveness in guiding attention. In this regard, Chen and colleagues (2022) examined the influence of stimulus perceivability on spatial interference effects in a selective attention task, comparing gaze and non-gaze targets. They used eyes or infinity symbols as targets and despite different stimulus types, similar patterns of congruency effects were observed (Chen et al., 2022; experiment 2).

This reversed congruency effect for the infinity symbols may be attributed to the specific shape used in the stimuli. Future research could explore not only different shapes but also variations in contrast (e.g., uniformly black arrows or arrows with different shades) to further investigate their impact on attentional processing and the role of stimuli's perceivability.

In conclusion, the background may have introduced a perceptual confound, potentially reducing the directional power of the stimulus. In this regard, based on the observation of non-social stimuli in Román-Caballero et al., 2021a, Tanaka and colleagues (2024) proposed that increasing the difficulty of extracting relevant information utilizing stimuli embedded in a complex background could facilitate the reversed congruency effect for non-social stimuli. Due to selective inhibition, stimuli with complex backgrounds may be strongly inhibited or the inhibitory mechanisms may start earlier compared to those with simple backgrounds.

Building on these intuitions, we designed the second experiment using stimuli with backgrounds with similar contrasting colors, in order to increase task difficulty. However, future studies could employ alternative methods to control for the perceptual complexity of the background and manipulate it gradually, modifying the segregation demands in a continuous way.

In summary, our results suggest that manipulating the perceptual contrast between the pupil and sclera is not sufficient to generate an effect comparable to that elicited by gaze (RCE). This finding has several implications; however, many unresolved questions require further investigation. Future research will provide deeper insights into the role of the perceptive features of the stimuli and contribute to a more refined understanding of the present findings.

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