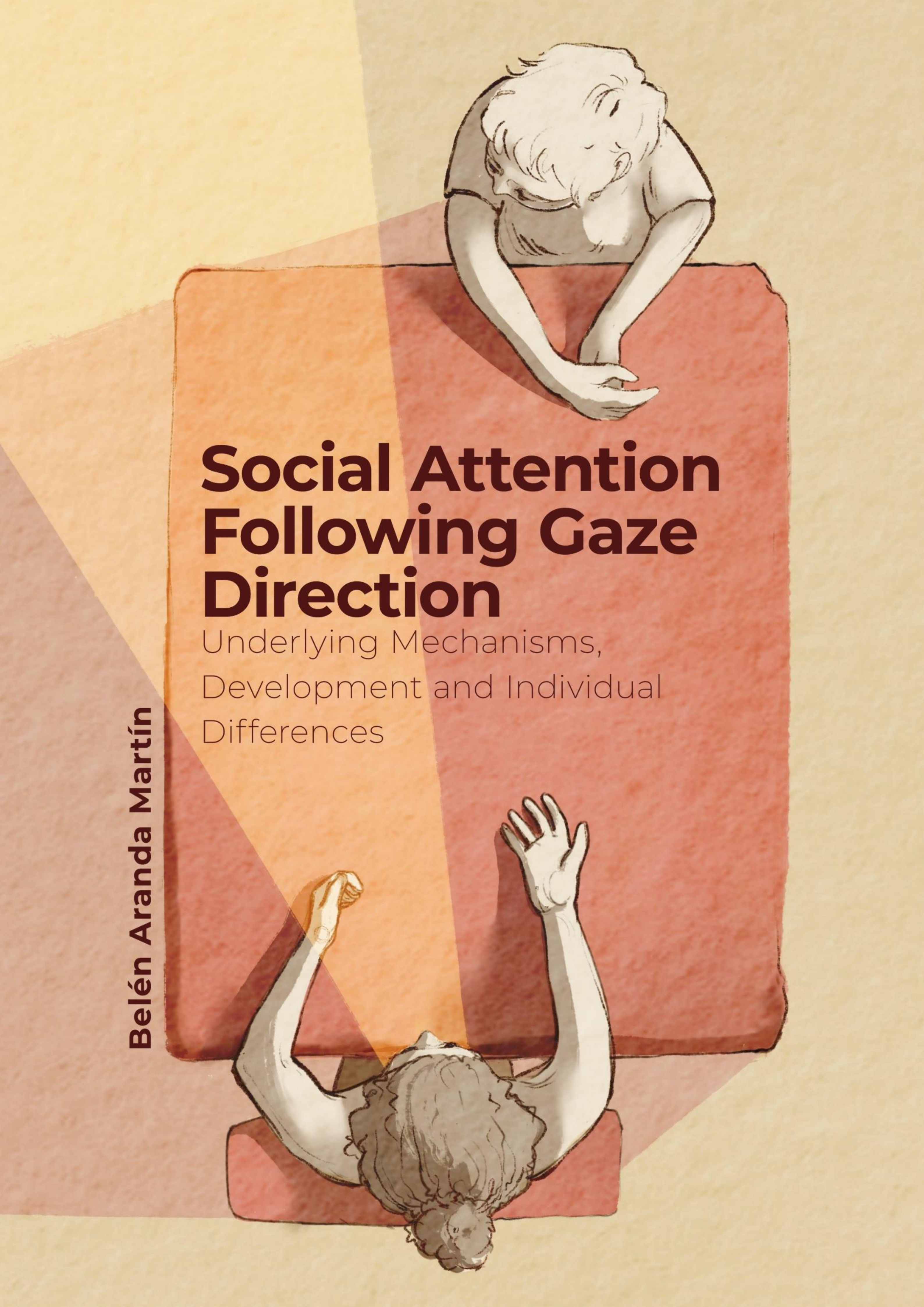

Social Attention Following Gaze Direction

Underlying Mechanisms, Development and Individual Differences

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Social Attention Following Gaze Direction:

Underlying Mechanisms, Development and Individual Differences

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A todas las mentes inquietas,

que buscan, escuchan y encuentran

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Resumen

Los ojos son una de las fuentes de información social más valiosas para los seres humanos. Se dice comúnmente que "los ojos son el espejo del alma", ya que nos ayudan a inferir los pensamientos, las emociones y el comportamiento de los demás. La importancia de la mirada es evidente tanto a nivel filogenético como ontogenético. Los ojos humanos tienen una morfología única entre primates que permite, con una esclera blanca y uniforme, detectar rápidamente la dirección de la mirada (Kano et al., 2022; Kobayashi & Kohshima, 2001). Esta habilidad especial en el procesamiento de los ojos está presente desde el nacimiento. Los bebés muestran una preferencia temprana por las caras (Farroni et al., 2005; Johnson et al., 1991) y son capaces de distinguir entre miradas directas y desviadas (Farroni et al., 2002, 2004). Progresivamente, la dirección de la mirada se convierte en una clave atencional precisa acerca del objeto de interés de las demás personas. Con la experiencia y el desarrollo cerebral, estas habilidades tempranas desencadenan una cascada de procesos cognitivos, como la atención conjunta, el lenguaje y la teoría de la mente, que son aspectos centrales en el diagnóstico, pronóstico e intervención de los trastornos del espectro autista (Mundy, 2018).

Por todo ello, los mecanismos atencionales en respuesta a la dirección de la mirada han suscitado el interés científico. En particular, se plantea un debate acerca de si la mirada se procesa mediante mecanismos generales, de forma parecida a otros estímulos que también dirigen la atención, como las flechas, o si, por el contrario, se procesa de manera especial. Aunque ambos estímulos producen un efecto similar de orientación atencional con algunos paradigmas experimentales (Chacón-Candia, Román-Caballero, et al., 2023), la mirada podría desencadenar mecanismos sociales adicionales en etapas posteriores de procesamiento (Edwards et al., 2022; Gregory & Jackson, 2017; Marotta et al., 2019). Para captar estas diferencias cualitativas, es necesario utilizar otros paradigmas que sean sensibles a efectos más allá de las propiedades atencionales compartidas.

Los estudios que conforman esta tesis se basan en un paradigma de interferencia espacial que ha logrado de manera consistente distinguir los efectos

atencionales producidos por la mirada de aquellos generados por las flechas (Cañadas & Lupiáñez, 2012; Hemmerich et al., 2022; Ishikawa et al., 2022; Jones, 2015; Marotta et al., 2018). En concreto, la mirada produce un efecto de congruencia opuesto al que suelen generar otros estímulos que carecen de naturaleza social. Este *efecto de congruencia revertida* específico de la mirada podría servir como un indicador indirecto de atención social, el cual intentamos comprender y analizar a lo largo de los siguientes capítulos. Así pues, el objetivo principal de la presente tesis es investigar *hasta qué punto y a través de qué mecanismos la mirada desencadena procesos atencionales específicos.* Abordamos este objetivo desde tres perspectivas complementarias.

En primer lugar, tratamos de desentrañar el mecanismo responsable de la reversión del efecto de congruencia de la mirada. Una posibilidad es que el procesamiento de la mirada active mecanismos adicionales específicos relacionados con su capacidad para transmitir intencionalidad. Percibir a una persona con la mirada desviada desplazaría nuestra atención en esa dirección, de manera similar a como lo haría la dirección de una flecha. Sin embargo, la mirada también prepararía al sistema atencional para seleccionar el posible objeto de interés al que esa otra persona está atendiendo. A través de los dos estudios presentados en el capítulo tres, exploramos detalladamente esta hipótesis investigando la influencia de una posible *distracción conjunta* que tendría lugar cuando los ojos se desvían fuera del entorno de la tarea.

En segundo lugar, buscamos esclarecer la contribución de factores sociales analizando la interacción del efecto con otras variables socio-cognitivas. En el capítulo 4, examinamos la influencia de las emociones en el efecto revertido y su interacción con diferencias individuales en el nivel de rasgos del espectro autista.

La tercera pieza clave para comprender las diferencias entre las flechas y la mirada surge en el contexto del desarrollo. En el capítulo 5, abordaremos cómo y cuándo emergen esos procesos atencionales específicos, considerando el periodo desde la infancia hasta la adolescencia.

Los resultados observados concuerdan con la literatura previa (Hemmerich et al., 2022; Itier & Batty, 2009; Marotta et al., 2019) en relación a la existencia de una primera fase de procesamiento compartida por los ojos y las flechas, seguida de un procesamiento adicional que solo ocurre con la mirada. Los mecanismos atencionales comunes parecen estar presentes en las niñas y niños de 4 años, mientras que el efecto de la mirada podría surgir progresivamente y asemejarse al patrón adulto a partir de la adolescencia temprana. Asimismo, factores sociales como la expresión facial de felicidad pueden incrementar la magnitud del efecto, una interacción que no se observa en personas con un alto nivel de rasgos del espectro autista. En esta compleja dinámica atencional, la mera percepción e identificación de objetos no parece suficiente para contrarrestar el mecanismo de distracción conjunta, lo cual no confirma la hipótesis planteada inicialmente. No obstante, a lo largo del capítulo 6, se exploran posibles marcos explicativos que amplían la concepción de la distracción conjunta y abarcan la existencia de un mecanismo adicional asociado con el procesamiento de la dirección de la mirada, que se perfeccionaría gradualmente durante la infancia y que podría verse afectado tanto por factores sociales del contexto, como por las características individuales.

Abstract

The eyes are one of the most valuable sources of social information for human beings. It is commonly said that 'the eyes are the window to the soul' as they help us infer the thoughts, emotions, and behavior of others. The importance of gaze is evident both at a phylogenetic and ontogenetic level. Human eyes have a unique morphology among primates, with a white and uniform sclera that allows for quick detection of gaze direction (Kano et al., 2022; Kobayashi & Kohshima, 2001). This special ability in processing eyes is present from birth. Infants show an early preference for faces (Farroni et al., 2005; Johnson et al., 1991) and can distinguish between direct and averted gazes (Farroni et al., 2002, 2004). Over time, gaze direction becomes an increasingly precise attentional cue regarding the object of interest for others. With experience and brain development, these early skills prompt a cascade of cognitive processes such as joint attention, language, and theory of mind, which are central aspects in the diagnosis, prognosis, and intervention of autism spectrum disorders (Mundy, 2018).

Attentional mechanisms in response to gaze direction have sparked a scientific interest. In particular, there is a debate about whether gaze is processed through domain-general mechanisms similar to other nonsocial stimuli that also orient attention, such as arrows, or if it is processed through a special system. Although both stimuli yield similar orienting effects (Chacón-Candia, Román-Caballero, et al., 2023), gaze may trigger additional social mechanisms in later stages of processing (Edwards et al., 2022; Gregory & Jackson, 2017; Marotta et al., 2019). To capture these qualitative differences, it is necessary to use experimental procedures that are sensitive to effects beyond shared attentional properties.

The studies comprising this thesis are based on a spatial interference paradigm that consistently differentiates the attentional effects produced by gaze from those generated by arrows (Cañadas & Lupiáñez, 2012; Hemmerich et al., 2022; Ishikawa et al., 2022; Jones, 2015; Marotta et al., 2018). Specifically, gaze elicits an opposite spatial congruency effect compared to other nonsocial stimuli. This distinctive *reversed congruency effect* of gaze may serve as an indirect index of

social attention, a phenomenon we aim to comprehend and analyze in the following chapters. Therefore, the primary objective of this thesis is to investigate to *what extent and through which mechanisms gaze triggers specific attentional processes.* We approach this goal from three complementary perspectives.

First, we aim to understand the underlying mechanism of the reversed congruency effect shown by eye gaze. One possibility is that gaze processing activates intentionality. On the one hand, perceiving someone with an averted gaze would shift our attention in the looked direction in the same way as perceiving an arrow. However, gaze may also prepare the attentional system to select the potential object of interest that the other person is attending to. Through the two studies presented in Chapter 3, we thoroughly explore this hypothesis by investigating the influence of a possible *joint distraction* effect that occurs when the eyes look outward, away from the task context.

Second, we seek to clarify the contribution of social factors by analyzing the interaction of this effect with other socio-cognitive variables. Chapter 4 examines the influence of emotions on the reversed effect of gaze and its interaction with individual differences in the level of autistic traits.

A third key aspect of understanding the differences between arrows and gaze stems from a developmental perspective. Chapter 5 addresses how and when these processes emerge, considering the period from childhood to adolescence.

The observed results align with previous literature (Hemmerich et al., 2022; Itier & Batty, 2009; Marotta et al., 2019) regarding the presence of an initial shared processing phase for eyes and arrows, followed by additional high-level processes specifically linked to gaze. Common attentional mechanisms appear to be present in 4-year-old children, while the gaze effect may gradually develop and reach the adult pattern in early adolescence. Our findings also indicate that other social factors, such as a facial expression of happiness, enhance the magnitude of the effect; an interaction that is not observed in individuals with a high level of autistic traits. In this complex interplay, mere perception and object identification may not be sufficient to counteract the presumed joint distraction mechanism. The overall data do not confirm the current joint distraction hypothesis. However, Chapter 6 delves into a comprehensive exploration of various expanded frameworks, encompassing the existence of an additional mechanism associated with gaze direction processing, which would gradually refine during infancy and be influenced by both social qualities of the context and individual characteristics.

Chapter 1

Introduction

Development of attention to gaze: Insights from phylogeny and ontogeny

“En tus ojos nazco, tus ojos me crean […]”

Miguel de Unamuno

The eyes and the act of gaze-following have captured the interest of a wide range of disciplines. This fascination with the eyes is evident even in folk sayings such as 'the eyes are the window to the soul'. Indeed, the eyes serve as a 'window' to emotions, mental states, and future behavior, giving them unparalleled biological significance for humans. Their morphology, which appears unique among other great apes, includes a uniformly and widely exposed white sclera that makes the direction of gaze more conspicuous and easier to detect, even under challenging visual conditions (Kano et al., 2022; Kobayashi & Kohshima, 2001). The eyes are also strategically positioned on the face, set forward and close together, allowing for enhanced depth perception and gaze following. Additionally, the eye region is emphasized by the prominent features in the human’s flat face, such as the cheekbones and eyebrows, highlighting the eye region (Emery, 2000). These particularities have emerged as an evolutionary solution that, while making it difficult to camouflage from predators, has increased the role of gaze as a communicative cue. Although non-human primates also use gaze as a signal for social interactions such as threat displays, courtship, communication about food sources and predators, and even asking for help, their usage is limited compared to humans. For example, while apes and monkeys can follow the direction of someone's gaze to a specific target, they do not use this ability to infer information about objects or mental states (Emery, 2000). In fact, in contrast to humans who typically prioritize information from the eyes, great apes rely more on other signals, such as head movements, to interpret social cues (Tomasello et al., 2007)

The underlying mechanism of gaze following, like other components of social cognition, comprises multiple factors from basic perceptual skills to complex and dynamic processes that enable social communication. Unraveling the ontogeny could be a key piece to understand this intricate puzzle. The first building blocks are already present in newborns (Goren et al., 1975; Johnson et al., 1991) and even fetuses (Reid et al., 2017) who exhibit a preference for face-shaped geometrical figures over the same features in a different configuration. Within days of birth, babies can already distinguish between faces with closed vs. open eyes (Batki et al., 2000) and discriminate between an averted and direct gaze, preferring to look at faces, either real or schematic, that engage in mutual gaze (Farroni et al., 2002, 2004). These preferences could owe to an immature visual system prepared to capture the visual pattern of faces including a top-heavy vertical asymmetry (Simion et al., 2002) and a face-specific light and shadow contrast polarity (Farroni et al., 2005). Moreover, these initial preferences extend to other sensory domains, with newborns showing different patterns of preferential orientation to the sounds (Kisilevsky et al., 2003) and smell (Porter & Winberg, 1999) of their caregivers. Besides being essential for the survival of babies, the early connections with their caregivers are also mutually reinforcing, increasing opportunities for social interaction and initiating a cascade of cognitive processes (Shultz et al., 2018). Therefore, along with this initial preference, exposure to faces and different contingencies in rich social contexts within sensitive periods would prompt the specialization of the social brain (Johnson et al., 2005).

In this line, a dual neural system for face and gaze perception has been proposed (Morton & Johnson, 1991; Senju & Johnson, 2009), suggesting the existence of two processing routes. The first one would be a subcortical route (described by Johnson and Senju, 2009, as a “fast track modulator”) that streams from the retina to the superior colliculus, the pulvinar, and the amygdala. This fast visual path operates with low spatial frequency information and would be involved in initial and rudimentary face processing, detecting and allocating attentional resources to face-like stimuli and, particularly, to the eyes. Similar to the Conspec system proposed by

Morton and Johnson (1991)[1], the subcortical mechanism would be responsible for the early preferential bias to faces and direct gaze observed in newborns, even in the absence of a fully functional cortical system. Subcortical inputs would activate slower cortical circuits modulating more complex processing of social signals, such as emotion, intentionality, gaze direction, or facial identity (Senju & Johnson, 2009). Through postnatal experiences, this route would undergo a progressive specialization “narrow down the initially widespread effect of eye contact” (Senju & Johnson, 2009, page 132). Moreover, the flow of information seems to be bidirectional, as top-down modulation derived from different task demands can also affect the early phases of gaze processing (Burra et al., 2019; Hadders-Algra, 2022)

Amidst the rapid social and developmental changes that occur during the first year of life, there is a notable improvement in the ability to track and interpret gaze. Starting from simple orienting mechanisms to physical movement, which could even be present in neonates (Farroni et al., 2004), infants progressively acquire a more nuanced understanding of the referential function of gaze, which involves recognizing that someone's gaze is directed towards a specific object or event. This allows infants to detect and identify objects with increasing accuracy and precision. As early as 4 months of age, infants exhibit a proto-gaze-cueing behavior limited to situations when a direct gaze is followed by an evident pupil motion (Farroni et al., 2000; Hood et al., 1998). However, this basic mechanism is yet not specific and could indicate sensitivity to directed motion. In contrast to adults (Bayliss et al., 2004), infants are more likely oriented by head movements when head and gaze indicate incompatible directions (Farroni et al., 2000; Farroni et al., 2003) or even when the eyes of their interaction partner are closed (Brooks & Meltzoff, 2005). In fact, evidence from event-related potentials (ERPs) of 4-month-old infants suggests that eye direction is still not dissociable from a more general face-sensitive component, such as the N290 (equivalent to the adult’s N170) (Johnson et al., 2005). This pattern

[1] The Two-Process Theory was initially proposed to explain the development of face processing in humans. CONSPEC refers to a subcortical route dedicated to detect faces of conspecific. This neonatal inputs would bias the specialization of a cortical social network involved in a more in-depth processing, such as face recognition, being termed as the CONLERN system. (Morton & Johnson, 1991)

seems to become more specialized with development, as adults show a distinct activation with eye direction (see, for example, Wicker et al., 1998).

By 6 months of age, infants can track the adult's eye or head movement to the gazed target within their visual field, but their target detection depends on various factors, including the intrinsic attentional characteristics of the object and whether it is the only one present in the infant's visual field (Butterworth & Jarrett, 1991). A more specific connection between gaze and object location has been observed in 9-month-olds, who are biased to attend to eye gaze rather than head movement. Still, a preceding direct gaze may be necessary for gaze-following (Senju et al., 2008). Infants around this age, from 6-10 months of age, also show a specific modulation in the amplitude of some ERPs components, such as the aforementioned N290, in response to a gaze shift. This differential ERP effect seems to be experience-dependent, as sighted infants with blind caregivers do not show it. This absence of the effect is likely attributed to their limited exposure to visual social interaction (Vernetti et al., 2018), further supporting the idea of a progressive specialization path.

As infant approach 12 months of age, their gaze-following abilities become more sophisticated. Their accuracy following gaze to target increases, with infants using a geometric mechanism to extract the intersection of their caregiver's line of sight within their visual field (Butterworth & Jarrett, 1991). Furthermore, these new skills are hints of a growing insight that “looking” means “seeing”, as attentional orienting becomes contingent on faces with open eyes (Brooks & Meltzoff, 2002). Finally, between the ages of 12 and 18 months, the mechanism of gaze-following extends beyond their visual field, searching for the potential attended object even when it is hidden behind a barrier (Butler et al., 2000; Butterworth & Jarrett, 1991; Mastergeorge et al., 2020; Meltzoff & Brooks, 2008; Moll & Tomasello, 2004).

Understanding that an adult may look at something outside their line of sight requires a broad understanding of the referential nature of gaze, which is central to joint attention. Joint attention involves two individuals that coordinately attend to a common point of reference and is supposed to be a foundational landmark upon which more complex cognitive and social abilities are built (Mundy, 2018). Although this basic definition is commonly reported in the literature, different perspectives have resulted in various definitions that combine different levels of social attention (Siposova & Carpenter, 2019). At its core, joint attention encompasses a set of socio-cognitive skills with a dual function in human social interactions: responding to a social partner's attentional bids, like following their gaze or initiating a shared attentional act. These skills are socio-communicative milestones implicated in a multitude of cognitive processes such as language or the Theory of Mind (Brooks & Meltzoff, 2005; Çetinçelik et al., 2021; Charman et al., 2000). As language is often acquired incidentally during social interactions between adults and children, tracking the referent of an adult's attention would aid in associating verbal labels with the attended object. Numerous studies have found that the frequency of gaze-following behaviors before the first year of life, and the ability to locate targets at 15 months, are related to increased vocabulary, expressive language, and mentalistic abilities months later (Brooks & Meltzoff, 2005; Çetinçelik et al., 2021; Delgado et al., 2002). Furthermore, following another person's attention towards objects enhanced learning about those objects compared to simply looking at them for an extended period (Okumura et al., 2017).

The influence of gaze on object learning, including their physical properties and their associated verbal label, follows a trend of increasing specialization during the first two years of life. By this age, toddlers use gaze direction to map labels onto objects even in conflicting situations. For example, 24-month-old children, but not 18-month-olds, choose the object that was gazed at by an adult even if it is less salient than other objects. These improvements are supported by other information processing developing capacities, such as memory and attention (Çetinçelik et al., 2021). Progressively, children not only understand the referential function of gaze direction but also attribute mental states. For instance, between 3 and 4 years of age, children can infer desire based on what their social partner is looking at (Lee et al., 1998).

However, it takes a few more years for children to understand more complex mental processes, such as learning that gaze can provide hidden but authentic information. For example, in an experiment conducted by Freire et al. (2004), adults verbally lied to children about the location of a toy while their gaze revealed its true location. While 3-year-old children were deceived by the verbal instruction, 5-year-olds inferred the correct location based on gaze direction. As Theory of Mind progresses, children seem to understand that there can be a discrepancy between what is said and what is done, and gaze plays a particularly important role in this type of non-verbal communication. Even adults with fully developed language and mentalizing skills rely on gaze direction reflexively. An illustrative example of this is magic tricks where a performer's gaze direction can be used to misdirect the audience's attention. People are more likely to be deceived when eyes are used as a misdirecting cue, especially when directed toward objects (Hergovich & Oberfichtner, 2016). For instance, the vanishing ball illusion is most effective when the magician's gaze follows the presumed movement of a ball that eventually will be thrown away. The gaze-following behavior reinforces the perceptual illusion that the ball is still present, reinforcing the disappearing impression when the magician eventually opens their hand (Kuhn et al., 2010).

Importantly, the acquisition and frequency of gaze following and joint attention behaviors have even been used as a tool for the diagnosis and prognosis of children with atypical socio-cognitive development, such as Autism Spectrum Disorders (ASD), being key targets for early interventions (Kasari et al., 2008, 2022; Mundy & Bullen, 2022). ASD is a heterogeneous developmental disorder characterized by early impairments in social communication as well as restrictive or repetitive patterns of behavior and interest, and differences in sensory responses (American Psychiatric Association, 2013). Children and adults with ASD often show a reduced orientation to socially salient stimuli and communicative cues which can negatively impact some other socio-communicative skills (Chawarska et al., 2013; Franchini, Glaser, De Wilde, et al., 2017). Specifically, an altered frequency and quality of joint attention behaviors is a central early symptom of ASD. Although protodeclarative skills are primarily impaired in children with ASD, such as initiating joint attention to share information, they also manifest an atypical response to others' bids for joint attention, such as following gaze or a pointing gesture (Mundy, 2018). Other important skills related to learning from and about others, such as imitation or symbolic play, are also impaired. Besides, children with ASD spend more time unengaged or solitary engaged with objects (Adamson et al., 2004), showing additional low-level attentional difficulties such as an increased difficulty to redirect attention (Jaworski & Eigsti, 2015).

Although there are mixed results regarding to what extent is gaze following affected in ASD (see Nation & Penny, 2008 for a review), children with this condition seem to successfully process the predictive value of directional cues, as evidenced by reflexive attention-orienting responses to social and nonsocial stimuli similar to those of their typically developing peers (Chawarska et al., 2003; Ristic et al., 2005; Vaidya et al., 2011). The differences in ASD may rely on the spontaneous and efficient use of gaze as a social cue rather than in the capacity to orient attention following gaze direction (Mundy & Bullen, 2022). While attentional orienting to gaze cues is similar in individuals with or without ASD, this does not rule out the existence of different underlying mechanisms that traditional Posner-like cueing paradigms may not be able to capture (Posner, 1980). For example, 2-year-old children with and without ASD exhibit similar orienting responses to social and nonsocial cues. However, typical development toddlers take longer to initiate saccades toward targets cued by gaze compared to nonsocial cues, this different pattern being absent in the ASD group (Chawarska et al., 2003).

These findings may suggest that neurotypical children incidentally use a distinct and presumably more elaborate processing strategy for gaze, which is not present in children with ASD (Chawarska et al., 2003; Johnson et al., 2005). Similar results were found using this same paradigm with adults. Although the cueing effect of arrows and gaze cues was identical in adults with and without ASD, neurotypical adults showed a longer response time to gaze than to arrows cues, whereas no differences were found in individuals with ASD (Vlamings et al., 2005). Interestingly, adults with ASD, but not neurotypical adults, have been found to adjust their orientation to faces according to the task demands. In a study conducted by Del Bianco et al. (2018), participants watched a social interaction scene but were asked to report different outcomes ranging from free visualization, finding an object, or inferring a mental state from the actor's gaze. Typically developing individuals showed an overall increased looking time to faces regardless of the task at hand, whereas this behavior was task-dependent for adults with ASD, being increased in the gaze-reading condition.

Taken together, the available evidence suggests that humans are inherently attuned to the social domain, with the ability to follow gaze direction having an early onset. The developmental trajectory of this skill progresses from a simple directional signal to indicating the precise focus of attention even when it is outside the visual field (Butterworth & Jarrett, 1991). This mechanism may build on a domain-general mechanism that gradually evolves to more complex and sophisticated social processes (Mundy & Bullen, 2022), such as using gaze as a gate to other people's minds. Based on all the above information, it seems plausible that gaze could produce distinctive attentional orienting effects. During the last decade, numerous studies have compared gaze with other stimuli that convey directionality and induce attentional shifts, but lack the social nature of gaze. This approach aims to discern the shared and potentially unique contribution of gaze to the attentional process. Further discussion on this topic will be presented in the following section.

Attentional orienting with social and nonsocial cues

"Y encontrar nuestros ojos

mirándonos desde la interioridad de la sangre.

Hablamos un lenguaje de jeroglíficos"

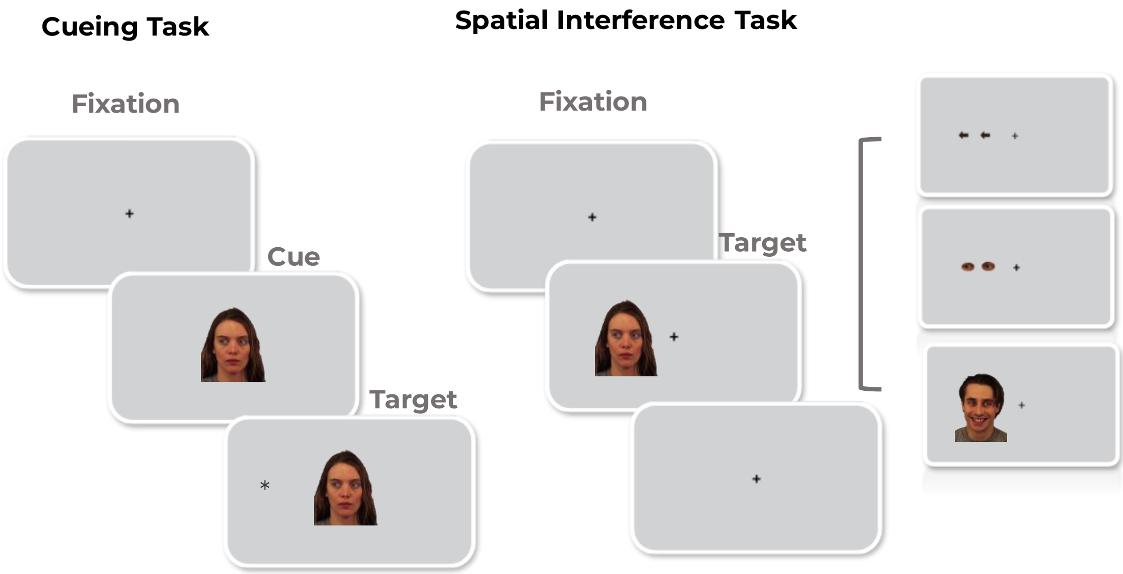
Gioconda Belli

Humans deal with vast amounts of information. In order to adjust our behavior to such a complex world, we need cognitive mechanisms to select information and process it efficiently. According to Posner's classic model (Posner, 1980), allocating attention towards a source of information, either automatically directed by stimuli (i.e., exogenously) or by voluntary top-down control (i.e., endogenously), results in selective processing of that input. The orientation could involve a visible change in eyes or body movements (i.e., overt attention) or a shift in spatial attention that may not have a noticeable visual correlate but can be identified by improved efficiency in target processing, as evidenced by faster reaction times (i.e., covert attention). As discussed in the previous section, the eye gaze is a valuable visual orientation cue since it provides insight into other people's focus of attention. Whether gaze attentional shifts are the results of specific social mechanisms, such as attribution of intentions and mental states (Apperly & Butterfill, 2009), or instead involve domain-general attentional processes elicited by stimulus directionality (Cole & Millett, 2019; Heyes, 2014), is a matter of ongoing debate. To address this question, eye gaze has been compared to other directional stimuli, such as arrows, which also convey symbolic directional information that is common in our daily lives and elicits shifts in spatial attention. However, unlike gaze, arrows lack the social ability to convey intentionality.

The cueing paradigm (Friesen & Kingstone, 1998; Posner, 1980) has been widely used to measure spatial attentional orientation, incorporating diverse variations such as changes in cue duration or predictability, or the use of different types of targets. As represented in Figure 1, this task usually involves a central fixation point followed by a directional stimulus, such as eyes or arrows, indicating left or right. After a variable interval of time (Stimulus Onset Asynchronie-SOA), a target appears randomly at the cued (congruent) or uncued (incongruent) location, and participants must detect, locate, or discriminate the target by pressing a key. Both gaze and arrows are effective orienting cues that facilitate target processing in the cued location, resulting in the so-called "cueing effect": faster and more accurate response to cued than to uncued targets. This attentional shift was previously thought to be under voluntary control, with both gaze and arrows serving as central symbolic cues. Unlike sudden peripheral non-predictive cues that automatically orient attention, it was assumed that symbolic cues should predict the target location for orientation to occur.

Figure 1

Illustration of Procedure in a Cueing vs. a Spatial Interference Task



Note. The cueing task (left panel) depicts a valid trial with gaze directed to the target location. The spatial interference task (right panel) depicts a congruent trial with a left-located face looking at the left. The stimuli in the figure are enlarged for illustrative purposes.

Nevertheless, neither gaze nor arrows fit completely into this classification. As expected from central symbolic cues, both produce long-lasting facilitation effects on target processing, even with extended cue-to-target intervals (Ristic & Kingstone, 2012). However, not only gaze but also arrows produce a shift of attention in the cued direction when they were unpredictive or even counterpredictive of the target appearance (see Dalmaso et al., 2020; Frischen et al., 2007 for a review). Despite this complex attentional profile and the great methodological heterogeneity within this literature, recent metanalytic results have shown that gaze and arrows produce a quantitative identical cueing effect (Chacón-Candia, Román-Caballero, et al., 2023). Moreover, the effect was moderated by some factors, such as the cue-to-target interval, with shorter intervals producing a larger cueing effect that was longer-lasting when cue and target overlapped in time, and the required response to targets, obtaining greater effects in discrimination and location than in detection tasks. It should be noted that all of these moderators seem to affect gaze and arrow cues equally.

Therefore, based on current data, the cueing effect seems to be a general measure of spatial attention which is a shared property of directional stimuli. This does not mean that the effects of gaze are limited to orienting attention in space but rather that a quantitative approach like this may be not sufficient to fully understand the social attention phenomenon (Capozzi & Ristic, 2020). For instance, Ristic et al., (2002) compared attentional orienting to gaze and arrow cues in children and adults, finding a not surprising identical pattern of results for both stimuli. However, research involving split-brain patients suggests that this attentional orienting might occur through different mechanisms. While attentional orientation for arrows occurred equally regardless of the hemisphere in which the targets appeared, with gaze it only occurred with targets that appeared in the right hemisphere, which is associated with face perception. To distinguish the basic shared attentional processes from the specific social contribution of gaze, it may be necessary to adopt a different approach that would be sensitive to qualitative differences (Chacón-Candia, Román-Caballero, et al., 2023; Marotta et al., 2012).

In this context, using variations of the original paradigm, some authors have shown how gaze and arrows produced similar orienting effects but triggered different selection mechanisms. For example, Marotta et al. (2012) modified the "two rectangle paradigm" (Egly et al., 1994) by using central and non-predictive gaze and arrow cues. Targets appeared at either end of one of two tilted rectangles. The tilt of the rectangles caused one end to align with the horizontal line on both sides of the central cue, while the other end coincided with the vertical line. This arrangement allowed for targets to be positioned at either the specifically cued or uncued location (i.e., the cued vs. uncued end of the rectangle), as well as within the cued or uncued object, i.e., the above or below the end of the tilted rectangle. Arrows and gaze equally facilitated the detection of the cued target locations compared to uncued ones, demonstrating a similar cueing effect. However, the selection mechanism followed a distinct pattern. By cueing a part of the rectangle, arrows seemed to spread attention throughout the whole object resulting in faster target detection within the indicated rectangle even when the targets were located at the opposite end. When initiated by gaze, the attentional orienting seemed to be more precise, selecting the exact gazed location (for a replication see Chacón-Candia et al., 2020). This does not imply that gaze cannot produce object-based orientation, as it does when the entire object is the actual focus of attention (Marotta, et al., 2013). Rather, it highlights the capacity of gaze direction to constrain attention to a specific and potentially interesting location. Similarly, recent findings (Chacón-Candia, Lupiáñez, et al., 2023) indicate that compared to arrows, the attentional orientation induced by gaze cues might be more specific, restricted to what is perceived as the site of interest looked at.

These results align with the idea that gaze is encoded according to its referential function. Gaze direction may implicitly trigger the “search for” an object of interest, which forms the basis of joint attention — the act of attending to what another person is attending to and learning about it. This automaticity in selecting the looked-at location is also manifested in other attentional effects, such as the Inhibition of Return (IoR). Typically, IoR is shown by sudden peripheral cues (such as a flashlight) that automatically orient attention to their location. When a target appears shortly after the exogenous cue (within 300 ms), a facilitation effect occurs, resulting in shorter reaction times for valid trials compared to invalid ones. However, after a longer period, reallocating attention to the same location as the cue would entail a bigger cost than attending to an uncued location, leading to longer reaction times for targets on valid compared to invalid locations. This cost is characterized as the attentional mechanism of IoR and may underpin the inherent search for novel information in the environment (Lupiáñez et al., 2013; Martín-Arévalo et al., 2013). It should be noted that when the exogenous cue is replaced by a central gaze, it could also produce IoR. Certain specific circumstance should occur for a gaze to induce IoR, such as a long enough SOA (2400 ms) and the presence of an event at fixation that trigger attention away from the cued location (Frischen, Smilek, et al., 2007). Still, it is intriguing that gaze yields this automatic form of attentional selection, despite being a symbolic cue whose attentional orientation is assumed to be endogenous.

Interestingly, gaze did not induce IoR in individuals with ASD (i.e. Asperger) who indeed manifest IoR with peripheral cues, reinforcing the idea that this dissociation may be related to social aspects that are automatically associated with gaze (Marotta, Pasini, et al., 2013). Additionally, these gaze-IOR effects follow a different and relatively late developmental onset. While 6-year-old children showed IoR with peripheral cues, gaze did not induce it until 9 years of age (Jingling et al., 2015). However, from 6 to 8 years, children exhibited the gaze cueing facilitation effect, suggesting that the presumed habituation to eyes required for gaze-induced IoR needs more time to fully mature. Similar to the developmental path described in the first year of life, layers of social refinement and maturation will gradually overlap, shaping the development of gaze orientation from rudimentary directional perception to more sophisticated and finely-tuned attentional processing.

In this line, the referential function of gaze could be crucial in many subsequent processes of target processing. For example, Gregory and Jackson (2017) have shown that the influence of gaze cues goes beyond mere orientation and impacted visual working memory. They combined the classic cueing paradigm with a recognition task in which participants had to report whether a colored square (out of a previously shown display of 4, 6, or 8 squares) had been presented. Interestingly, while both cues produced similar cueing effects in perception (when responding to the target), only gaze, but not arrows, led to better recall of previously cued targets. In a subsequent experiment, the authors added barriers on both sides of the central face. In the closed barrier condition, an opaque rectangle occluded the line of sight between the cue and the targets, and participants were informed that the face could not see them. In the open barrier condition, a white gap was shown, interpreted as a window through which the targets were visible. Interestingly, while the gaze's cueing effect was present regardless of whether the barrier was open or closed, a better recall of gaze-cued items was only observed in the condition where the barriers were open (Gregory & Jackson, 2019). These findings suggest that the unique role of gaze in target processing is likely related to intentionality reading.

This gaze-specific effect has been shown to extend to long-term memory (Dodd et al., 2012). In this study, a word (out of 32) could appear at either side of a central schematic face cue that could look at or away from the word. Participants were asked to recall as many words as possible at the end of the task. The anticipation of this final memory test was manipulated through different experiments so that participants could be aware or unaware of the upcoming memory test. Regardless of this intentional or incidental word encoding, when using SOAs shorter than 1000 ms, gazed words were better recalled than the non-gazed ones. Arrows, however, did not yield any difference in memory performance.

There are other post-perception effects in which the influence of gaze appears to differ from that of arrows, such as object likability. Bayliss et al (2006) tested this effect in an object categorization task using central and irrelevant arrow and gaze cues. They hypothesized that when we see someone looking at an object, we not only infer where their attention is directed but also that they may manifest a preference for that object. This preference could have implications for our own evaluation of objects, which is not supposed to be caused by nonsocial stimuli, like arrows. The authors indeed found that, despite the similar cueing effects for arrow and gaze cues, the looked-at objects were rated as more likable than non-gazed ones, an effect that was not found with arrows. In a posterior study, similar to the previously discussed memory effect (Gregory & Jackson, 2019), authors tested the gaze-liking effect by adding two occluding panels on both sides of the central face, creating a condition where the face was perceived as able or unable to see targets depending on the position of the barriers. While barriers did not affect the cueing effect, they did influence the liking effect which only occurred in the conditions where faces are supposed to see the targets (Manera et al., 2014). However, this preference has been also found using written descriptions of gaze *("Michael looked toward the/away from the…")* and even arrow direction *("An arrow pointed towards the/away from the…")* (Tipples & Pecchinenda, 2019). Even though this manipulation results in a greater liking effect compared to arrows, this effect does not seem to be exclusive to gaze stimuli and does not require a shift of spatial attention to produce it.

In summary, the data suggest that arrows and gaze orient attention in the indicated direction similarly, as evidenced by the equivalent facilitation of cued and uncued targets. However, qualitatively different mechanisms could subserve the attentional selection (Chacón-Candia et al., 2023; Marotta et al., 2012), and may have implications on the post-perceptual processing of targets, such as memory (Dodd et al., 2012; Gregory & Jackson, 2017) or affective evaluation (Bayliss et al., 2006). Looking where someone else is looking may incidentally trigger additional high-level factors related to the expected goal of gaze direction: indicating the focus of attention of a social partner. The presumed selection of the object of interest appears to be automatic, as seen in gaze-induced IoR, and, unlike the one produced by peripheral cues, may have a late developmental onset (Jingling et al., 2015) and could even be disrupted in populations with atypical socio-cognitive development (Marotta, et al., 2013). Moreover, the post-perceptual effects of gaze could be reduced or eliminated when conveying intentionality is not possible, as with occluding barriers (Gregory & Jackson, 2019; Manera et al., 2014), supporting the idea that high-level factors underlie gaze processing.

So far, arrow and gaze differences have been revealed using various adaptations of the cueing paradigm where both gaze and arrows act as directional cues that are processed to detect, locate, or identify a target. Nevertheless, stronger evidence of dissociation can be found when social or nonsocial stimuli are presented as targets instead of cues.

Arrow and gaze differences in a spatial interference task: The Reversed Congruency Effect

"No es que vea algo diferente,

sino que uno ve de forma diferente.

Es como si el acto espacial de ver

estuviera modificado por una nueva dimensión"

Carl Jung

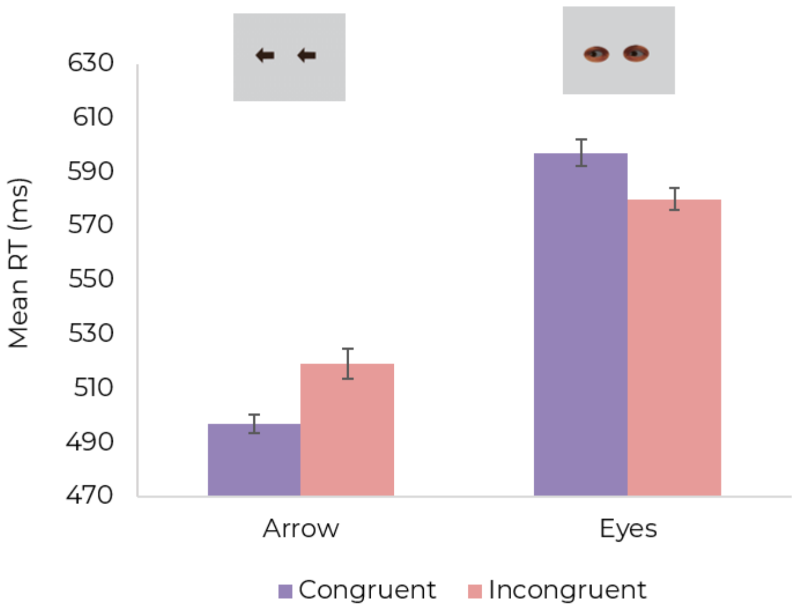
Although attentional orienting by arrows vs. gaze can be dissociated with some paradigms in which arrows and gaze are used as orienting cues, a clearer and robust dissociation of nonsocial and social stimuli has been found using a spatial interference task where gaze and arrows are targets instead of cues. Contrary to the cueing paradigm discussed in the previous section, the direction does not indicate the possible location of an upcoming target but it is the target itself (see Figure 1). These tasks require participants to identify the direction of targets while ignoring their location. The interference between the location and the indicated direction creates two conditions of congruency. Congruent trials occur when the direction indicated by the stimulus matches its spatial location (e.g., a right-located arrow pointing to the right), while incongruent trials occur when the two dimensions do not match (e.g., a right-located arrow pointing to the left). In spite of location being irrelevant to the task, the mismatch with the relevant attribute (direction) usually results in a spatial congruency effect, evidenced by faster and more accurate responses in congruent conditions compared to incongruent conditions (Kornblum et al., 1990). This effect has been observed with various symbolic stimuli that indicate direction based on their physical or semantic qualities, including words (such as "left" or "right") and arrows (Funes et al., 2007; Liao & Wang, 2015; Lu & Proctor, 1995; Virzi & Egeth, 1985).

Cañadas and Lupiáñez (2012) investigated spatial interference using gaze as the directional cue. After the appearance of an initial fixation cross, a face or a pair of eyes with a direct gaze were randomly displayed to the right or left side. Following a variable SOA (0, 75, 150, or 250 ms), the same face was displayed with a left or right-averted gaze. Participants were required to identify the direction of the eyes as fast and accurately as possible irrespective of their location, creating congruent and incongruent conditions. Surprisingly, the authors found the opposite effect to the standard congruency effect typically observed with nonsocial stimuli. Gaze produced a Reversed Congruency Effect (RCE): faster and more accurate responses in incongruent than in congruent conditions. It is noteworthy that the reversion occurred even without a perceived gaze shift, as it was found either with a direct gaze preceding the target (e.g., 250 ms of SOA) or when only the averted gaze was presented (e.g., with 0 ms of SOA).

The authors replicated the RCE with faces and isolated eyes, but not when using two inverted triangles which yielded a standard congruency effect even when embedded between two lines resembling moving “pupils” and some participants were encouraged to think of them as eyes. Therefore, this opposite congruency effect was hypothesized to capture special attentional features of gaze orienting, not produced by other nonsocial stimuli. In a later study, the results were replicated by directly comparing cropped eyes with arrows presented in two different blocks of trials (Marotta et al., 2018). The dissociation was clear: while the arrows produced the standard congruency effect, the gaze response was reversed (see Figure 2 for a representation of the observed results).

Figure 2

Graphic Representation of the Congruency Effects of Arrows and Gaze



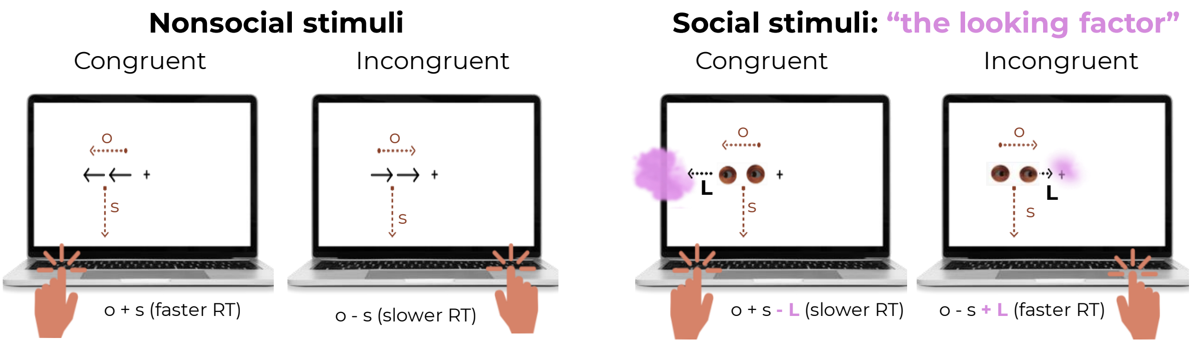
Note. Graphical recreation of the results obtained in Marotta et al. (2018) where arrows show a standard congruency effect and eyes show a reversed congruency effect.

Opposed but coexisting factors

Considering the comparable attention-orienting properties of gaze and arrows (Chacón-Candia, Román-Caballero, et al., 2023), the fact that gaze yields the opposite effect to nonsocial stimuli becomes particularly noteworthy. As previously discussed, both gaze and arrows involve an overlapping set of attentional processes, but the social nature of gaze can generate additional effects, as demonstrated by the RCE. In the case of the spatial interference task, as depicted in Figure 3, the appearance of arrows and eyes produces the spatial activation of their location (the spatial vector represented by "s") followed by an attentional shift towards the pointed or gazed direction (the orienting vector represented by "o"). These two opposite forces would lead to the location-direction interference shown by social and nonsocial directional stimuli. However, gaze must also add a specific mechanism (the "looking factor" represented by "L") that reverses the final observed effect.

Figure 3

Common and Unique Components in Gaze and Nonsocial Stimuli in the Spatial Interference Task



Note. The picture illustrates the hypothetical factors (represented by dotted arrows) in the spatial interference

The coexistence of shared and dissociable components has been supported using the same spatial interference paradigm but mixing social (eyes or a face) and nonsocial stimuli (arrows or words) within the same block of trials (Hemmerich et al., 2022). The results replicated the dissociation between gaze and arrows in the congruency effect, with gaze yielding an RCE and arrows producing a standard effect. This suggests that the RCE can occur even when gaze and arrows are manipulated on a trial-by-trial basis, indicating that it does not depend on adopting a global strategy or establishing a certain task set adapted to the stimulus.

Furthermore, a within-block manipulation allowed the analysis of sequential effects of congruency (Gratton et al., 1992). This phenomenon outlines conflict adaptation, showing that prior experience with conflict can facilitate its subsequent resolution. Importantly, these sequential effects have been shown to be conflict-specific, meaning that the performance benefit only occurs when the conflict to be solved has the same nature as the one previously experienced. For instance, experiencing a Stroop conflict prepares the system for another Stroop conflict, but not for a Simon one, and vice versa (Braem et al., 2014; Funes et al., 2010). Hemmerich et al. (2022) found that both arrows and gaze were influenced by previous conflict (the congruency condition in the previous trial) irrespective of the social or nonsocial nature of the preceding stimulus. In other words, gaze congruency in the previous trial modulates the congruency effect of arrows in the same way that arrows would do, indicating that the conflict produced by both stimuli is governed by shared mechanisms. However, how this modulation affects gaze and arrows highlights the diverging nature of each stimulus. Facing an incongruent trial, regardless of whether it was an arrow or a gaze target, reduced the standard congruency effect of a subsequent arrow trial but increased the RCE of a gaze trial. This seems to indicate that prior experience of conflict reduced the spatial interference that affected both arrow and gaze similarly but did not affect the unique and opposing effect of gaze, which lead to overall RCE for gaze and standard for arrows. These results also generalize across different nonsocial and social stimuli.

Thus, the RCE of gaze arises from the interplay of shared and unique effects, which work in opposing directions. Therefore, by reducing shared interference, such as after solving an incongruent trial, the effect of gaze appears to increase. This has been found not only in terms of conflict adaptation but also by modifying other parameters of target presentation. Across two studies, Roman-Caballero et al. (2021a and b) increased the perceptual complexity of targets by modifying their background with colored geometric shapes forming a mosaic, into which arrows or eyes were inserted. The authors found that complex figure-ground segregation of targets reduces the direction-location interference (Román-Caballero et al., 2021a) while increasing the RCE (Román-Caballero et al., 2021b). The perceptual dissociation required to select the target direction caused a "temporal delay" (Hommel, 1993) that makes the spatial code of the irrelevant location decay. By reducing the common interference, the specific effect of the RCE was better captured. This could play a role when using the entire face as the target, where segregating the background would lead to less location interference and thus an increased RCE compared to isolated eyes (see Cañadas and Lupiáñez, 2012, for comparing faces and cropped eyes, and Marotta, et al., 2018, for cropped eyes).

Further evidence in this line comes from event-related potentials (ERPs) (Marotta et al., 2019). On the one hand, this study replicated the arrow and gaze distinct behavioral effects (standard and reversed congruency effects, respectively). Interestingly, the congruency of both targets generated an identical modulation on early ERPs components (i.e., P1 and N1) but the opposite on later ones (i.e., P3 and N2), supporting the existence of shared early processing stages, such as the spatial coding and attentional orientation, and more complex gaze-specific mechanisms that occur in later processing stages. These latter, opposite, and presumable social effects would eventually lead to the RCE.

Emotional modulation

Additional evidence supporting the involvement of social factors in the RCE comes from studies examining emotional modulation. Although the RCE was found in every emotional condition, facial expressions of happiness and anger yielded a greater RCE than fearful or neutral expressions (Jones, 2015). According to the shared signal hypothesis (Adams & Kleck, 2003), happiness and anger are considered "approach-oriented" emotions while sadness and fear are considered "avoidance-oriented". Since in incongruent trials (i.e., a right-located face looking at the left), the gaze is directed at the center of the screen, where participants were also looking, it makes sense that "approach-oriented" expressions enhance gaze direction identification for inward-directed gazes compared to outward-directed (a more in-depth discussion of this hypothesis will be developed in the section: 3.4. "Three proposed mechanisms"). No matter whether in line with the shared signal hypothesis, the modulation of the RCE observed with gaze by emotional expression of gaze has been also observed by Torres-Marín et al. (2017; see below).

Other studies have failed to find an emotional modulation of the RCE (Tanaka et al., 2022). However, differences in design could undermine the emotional modulation, as authors presented upright and inverted faces mixed on a single block. Since emotional perception is closely tied to the orientation of the face, it is not surprising that the emotional modulation effect was not observed under these conditions. The authors also found an RCE responding to direction on inverted faces, suggesting that the RCE could be generated by local features (Langton et al., 2004). However, this effect may also be due to participants switching to a more functional processing style for eye direction detection under these particular conditions of a trial-by-trial face rotation, therefore processing individual parts of the face instead of the face as a whole.

Certainly, perceptual processes can help to elucidate the unique attentional effects triggered by gaze. In fact, the use of cropped eyes instead of faces was intended to perceptually match gaze and arrows, so that only a social explanation could be derived from the possible results. However, it is undeniable that they are inherently different stimuli and the social significance of eyes is closely related to their specific features. Thus, a total perceptual equalization with arrows is not only impossible but also undesirable. In a real-life situation, eye direction is perceived in a dynamic context, integrated with other cues such as movement, emotions, identity, or gender. Although adapting stimuli to laboratory conditions is necessary, we must not disregard these factors in order to draw meaningful conclusions about the influence of eye direction in social interactions. Alternatively, an effective strategy to investigate these two distinct stimuli is to examine how their effects interact with individual differences in social attention processes that are theoretically relevant.

Individual differences in the RCE

The spatial interference task using faces with neutral or emotional expressions has been tested with individuals who have high and low levels of gelotophobia, a personality trait characterized by a disproportionate fear of being laughed at by others (Ruch et al., 2014). It has been proposed that individuals with high levels of gelotophobia have difficulty attributing intentions to others, which can be interpreted by using different signals such as gaze direction and facial expression. Both individuals with high and low levels of gelotophobia showed an RCE that was modulated by facial expression, being happiness, anger, and—contrary to Jones's results (2015)—sadness the emotions that increased the RCE (Torres-Marín et al., 2017). Interestingly, gelotophobia did not modulate the RCE in terms of reaction time but did affect the percentage of errors, where individuals with high levels of gelotophobia showed a greater RCE than non-gelotophobes.

A different result was found in individuals who exhibit high levels of social anxiety (Ishikawa et al., 2021). In this study, arrows and cropped eyes were used as targets showing the expected standard and reverse effect for arrow and gaze, respectively. Moreover, anxiety traits correlated with the magnitude of the RCE, such that individuals with greater social anxiety scores showed a reduction of the effect, a correlation that was not found with arrows. While the mechanism behind the RCE remains unclear, its interaction with personality traits suggests that there could be social components at play.

Three proposed mechanisms based on gaze social nature

There has been a decade since the first mention of the RCE (Cañadas & Lupiáñez, 2012). Since then, some hypotheses have been proposed about the potential underlying social mechanism, though there is no consensus at the moment. The first hypothesis, suggested in the seminal paper of Cañadas and Lupiáñez (2012), is a presumed eye-contact effect. The perception of direct gaze seems to trigger preferential detection processes and enhances the allocation of attentional resources, which in turn modulates cognitive processing and behavioral responses (Conty et al., 2016; Senju & Johnson, 2009). For example, a direct gaze is detected more rapidly and facilitates the discrimination of approach-oriented emotions compared to an averted gaze. Note that in incongruent conditions of the spatial interference task, gaze is directed inwards, towards the same area where the participant is also looking (e.g., a left-located gaze looking to the right), while in congruent conditions it is directed outward. Participants may perceive the incongruent gaze as directed towards them, which speeds up their response, in contrast to congruent trials where the gaze could be perceived as directed away.

This **eye contact hypothesis** has been tested using an "implicit" version of the task in which participants had to identify the blue or brown color of the targets, either a pupil or arrow, instead of responding to their direction (Narganes-Pineda et al., 2022). Considering that eye-contact effects can occur implicitly, benefits derived from experiencing mutual gaze should be observed even when the direction is not explicitly attended to. However, no congruency effects were found for either arrows or eyes when identifying color, dismissing the eye-contact hypothesis. Nevertheless, when participants were explicitly asked to identify the direction of the targets, the distinct congruency effects of gaze and arrows were replicated, even when a verbal response was required instead of the classical lateralized key press (Experiment 3 of Narganes-Pineda et al 2022). These findings suggest that explicit processing of the direction of the stimuli is necessary for interference to occur whereas the response selection (either manual or verbal) does not seem to affect the results.

Another alternative interpretation of the mechanism behind the RCE is that the facilitation is caused by the establishment of **joint attention**. As depicted in Figure 3, during incongruent trials (e.g., two right-located eyes looking to the left, so that, to the center of the screen) gaze could lead participants to "jointly" look at the fixation point, thus enhancing direction identification (represented by the vector "L"). Some evidence supporting this hypothesis has been found by lateralizing the central fixation point and replacing it with an object (Edwards et al., 2020). The authors found that the direction of eyes looking at the fixation point, where the participant was instructed to fixate, was more accurately identified than when it was directed outward. Arrows would not generate joint attention as they are not a biological entity with intentionality or a "mind". Taking this idea further, some authors propose that these specific gaze effects might not depend on the presence of eyes, but rather on being perceived as having communicative intention, so that, in addition to eyes and arrows, the authors used faces of cats, fish, or robots (Ishikawa et al., 2022). Their results, besides replicating the eyes and arrows dissociation, indicate that the RCE is only present with humans and cats, with whom humans might have communication intention, but not with fish, with whom humans do not have communication experience, or robots who participants consider do not have intention.

Another explanation for the RCE that is not mutually exclusive with joint attention has also been proposed. In this case, the RCE could be explained by a potential disadvantage that occurs under congruent conditions when gaze is directed outward (i.e., outside the computer screen where the relevant information for the task appears). Coping with eyes during everyday social interactions may entail specialized mechanisms of incidental attentional search and selection of potentially socially relevant (i.e., looked at) objects. As shown in Figure 3, once attention has been oriented towards the gazed location (the "o" vector), gaze may trigger a default mechanism (the “L” vector) for searching for potentially relevant objects, even in the absence of any actual stimuli, as in congruent conditions where the eyes look outward, resulting in a "**joint distraction**" that slows down direction identification and contributes to the final RCE. Humans use eyes to infer not just where but also what another person is attending to. This intrinsic referential nature of gaze direction could prompt a search for the potential focus of interest where the attentional act would be completed.

A similar pattern has arisen from aesthetic perception studies. People tend to exhibit an "inward bias" when perceiving framed images, like photographs and paintings, preferring compositions where the depicted agents are facing inward rather than outward (Chen et al., 2018). In these experiments, participants often place characters with averted gazes in a way that suggests they are looking inward, while people with direct gazes are not preferentially placed in specific regions. The outward gaze of faces within a scene may diverts the observer's attention away (joint distraction) making it less aesthetically pleasing. This phenomenon can be exemplified by Picasso's renowned painting *Guernica* (Figure 4), where a disruption in the cohesive gaze pattern within the scene creates a bizarre social impression of disarray. In this artwork, the characters lack coherent eye contact and instead look in different directions, frequently outward, which contributes to the overall sense of disorder.

Figure 4

Reproduction of the Painting "Guernica" by Pablo Picasso

Note. Image obtained from the website of the Reina Sofia Museum. (https://www.museoreinasofia.es/coleccion/obra/guernica)

In light of the extensive research on this topic, it is evident that gaze plays a crucial role in human social interactions. Nonetheless, the attentional intricacies of this phenomenon remain poorly understood. This thesis aims to contribute to the ongoing exploration of the attentional qualities of gaze by using the RCE as a tool to better understand its potential uniqueness. In the following sections, we will explore both the underlying attentional mechanisms of the RCE, its developmental trajectory, and its interaction with individual traits.

Chapter 2

Aims and overview of research

Aims and overview of research

The broad picture described in the introduction section reveals the importance of gaze in human interactions and raises several open questions. One critical aspect to consider from an attentional perspective is whether the processing of gaze direction is governed by general attentional mechanisms or rather specific ones of a social nature. The latter perspective is particularly compelling, given the importance of gaze following in both phylogenetic and ontogenetic contexts. The ability to detect and use eye gaze as an attentional cue emerges early in development and, through experience and brain maturation, a cascade of socio-cognitive processes built upon this foundation. The information conveyed by gaze grows in complexity during infancy and childhood, progressing from transmitting coarse directional information to becoming more precise and informative about the attentional referent. This developmental progression promotes learning, language acquisition, and the incorporation of a wide range of mentalistic processes. Given the social and biological relevance of gaze, it is plausible to assume that the interplay between attentional orienting and object selection holds a unique role compared to other symbolic stimuli, such as arrows, which lack the inherent biological nature and communicative intention.

However, when using arrows and gaze as central nonpredictive cues, such as in Posner's cueing paradigm (Posner, 1980) (e.g. *gaze cueing,* Frischen & Tipper, 2004), both cues equally facilitate the processing of cued targets. This suggests that both may be processed through a general attentional domain. Nonetheless, the role of gaze in directing attention is complex and multifaceted, involving numerous ongoing processes, ranging from low-level attentional features to the integration of higher-level social processes. By just measuring gaze orientation we may overlook its social contribution. Indeed, alternative paradigms which explore not only "how much" gaze directs attention but also "how" it does so compared to arrows, have revealed differences in attentional selection following gaze direction (Chacón-Candia et al., 2020; Chacón-Candia, Lupiáñez, et al., 2023; Marotta et al., 2012) and its subsequent influence on target processing (Bayliss et al., 2004; Dodd et al., 2012;

Gregory & Jackson, 2017; Okumura et al., 2017). A clear example of attentional dissociation has been observed using a spatial interference task, with arrow and gaze direction serving as targets instead of cues. In this task, participants are instructed to identify the direction of a laterally presented target (arrow or gaze) while ignoring its location. While a standard congruency effect is evident in responses to nonsocial stimuli, with faster responses to congruent location-direction conditions than to incongruent ones, eyes elicit the opposite effect, resulting in faster responses to incongruent than to congruent conditions, a phenomenon known as *Reversed Congruency Effect* (Cañadas & Lupiáñez, 2012). Together, all these data suggest that spatial and attentional orienting effects, common to other directional stimuli such as arrows, converge with the triggering of unique social mechanisms in the processing of gaze direction.

The present thesis dissertation aims to *deepen the understanding of social attention by exploring to what extent and through which mechanisms the attentional processes underlying gaze processing are singular*. To answer these questions, we employed the spatial interference task, a well-established paradigm that has consistently demonstrated a dissociation between social and nonsocial stimuli in the spatial congruency effect (Cañadas & Lupiáñez, 2012; Hemmerich et al., 2022; Ishikawa et al., 2021; Jones, 2015; Marotta et al., 2018; Narganes-Pineda et al., 2022). In particular, our focus was on investigating the Reversed Congruency Effect (RCE) elicited by gaze. While this measure serves as an indirect index to approach a construct as elusive as social attention, which is our primary goal, uncovering the underlying mechanisms offers a dual advantage.

On one hand, understanding the underlying mechanisms of this effect is crucial to draw meaningful conclusions. While there are indications of social components at play, such as gaze automatically eliciting intentionality that may result in a unique form of attentional selection of gazed-at objects (Edwards et al., 2020), a definitive conclusion is still lacking. Therefore, clarifying the underlying mechanisms of this effect is essential to advance theoretical understanding. On the other hand, if the RCE is indeed capturing implicit socio-attentional mechanisms, the task could become a valuable assessment tool as it has several advantages not just for experimental research but for educational or clinical contexts. In laboratory settings, its simplicity allows for testing relevant theoretical modifications, such as altering targets (Román-Caballero et al., 2021b), adding emotional expression to faces (Jones, 2015; Torres-Marín et al., 2017), modifying target positions or incorporating new elements (Edwards et al., 2020). Additionally, it can be employed alongside measures of cerebral activity, such as electroencephalography or fMRI (Marotta et al., 2019, Narganes-Pineda et al. 2023). Moreover, it is easy to perform and administer, which makes it suitable for a wide range of populations with diverse chronological or developmental age ranges. The use of reaction times, an implicit and highly precise measure, not only provides an unbiased index but also allows the assessment of populations with limitations in oral communication.

We approached the proposed general aim from three angles. Firstly, in **Chapter 3** we attempted to unravel *the underlying mechanism of the RCE by testing the joint distraction hypothesis*. It proposes that when gaze looks outward, where there is no referent to look at, an automatic drive to search for the potentially attended and to be selected object could take place, slowing down direction identification and, ultimately, leading to the RCE. Two experimental series, comprising Study I and Study 2, cover this first set of questions. In **Study I**, we aimed to eliminate the joint distraction factor by adding some "to-be-looked" elements to the spatial interference task. Specifically, we introduced a surrounding bicolor frame in which one color was consistently presented at each end. The targets, either arrows or cropped eyes (which were presented in two separate blocks), were pointing to or gazing at one of the two colors. One group of participants followed the standard instruction to identify the direction of the targets, while another group focused on determining the color indicated by the arrows or the direction of the gaze. By altering the task conditions, we aimed to determine whether the RCE would still be observed when joint distraction was minimized or eliminated. Although the results of Study I did not confirm the joint distraction hypothesis, as the RCE persisted even when participants responded to the indicated color, we discussed possible methodological aspects that could explain these unexpected findings. The analysis plan and hypotheses of this study were preregistered at the Open Science Framework (https://osf.io/n7y36/) and its results have been published in *Psicológica Journal* (Aranda-Martín et al., 2023)

To expand the scope of our conclusions and further test the hypothesis of joint distraction, we conducted **Study II**. This second experimental series included several experimental manipulations, including substituting colors with real objects and adjusting the presence or absence of different elements across trials and blocks. Additionally, we investigated whether the mere presence of objects or actively responding to them would impact the occurrence of the RCE. The analysis plan and hypotheses of this study were preregistered at the Open Science Framework (https://osf.io/3h2ut/). The observed pattern of results was not in line with the *joint distraction hypothesis*, and possible alternative explanations and future direction of the research are discussed in Chapter 3.

Indeed, finding out which mechanism accounts for the RCE holds relevant theoretical implications in terms of comprehending whether or not attentional differences are influenced by social factors. Arrow and eyes are two hardly comparable stimuli, as they differ not only in their social significance and biological relevance but also in their perceptual demands. To overcome perceptual differences and gain a better understanding of whether the RCE is driven by social components, we adopt an individual difference approach, incorporating further social elements, such as emotions, to test for potential modulations. The experimental series presented in **Chapter 4** (**Study III**) aims to *examine the emotional modulation of the RCE by comparing two groups of individuals differing in their level of autistic traits.* Notably, people with ASD may exhibit an orienting response to gaze cues similar to neurotypical individuals, even when their sensitivity to gaze in natural or spontaneous situations is impaired. As previously discussed in the Introduction Section (Chapter 1), the gaze cueing effect, obtained from Posner-style tasks, may capture the directional properties shared with nonsocial stimuli. Taking the RCE as an index of a posterior added social process, people with high traits of ASD could manifest a different pattern of results in the spatial interference task compared to those with low autistic traits. This study has been published in the *International Journal of Environmental Research and Public Health* (Marotta et al., 2022).

Finally, in **Study IV** (**Chapter 5**) we aimed to *provide insights into when and how these attentional differences emerge on typical development, outlining the developmental course of the congruency effect of gaze and arrows targets across* *various age groups,* ranging from childhood to adolescence. The observed pattern of results showed a different developmental trajectory for the effects observed for arrows and gaze, leading to an interesting discussion about the potential mechanisms inherent to attentional orienting following gaze that could develop between infancy and adolescence. This study has been published in the *British Journal of* Psychology (Aranda-Martín et al., 2022b) and the results have also composed a popular science article published in *Ciencia Cognitiva* (Aranda-Martín et al., 2022a).

Finally, the **General Discussion** (**Chapter 6**) provides an in-depth analysis of our data in relation to the existing literature*, aiming to present an integrative view of empirical findings and underlying theories*. Specifically, we focus on the mechanisms that may underlie the specific effect of gaze, exploring whether it arises from social components or other low-level aspects. Based on the results obtained in this thesis, some possible approaches to the phenomenon are proposed, providing directions for future research that could shed light on this interesting effect.

Chapter 3

Underlying mechanisms

1 Study I

Attentional differences between gaze and arrows processing: Where vs. What are eyes looking at

This study has been published as:

Aranda-Martín, B., Ángeles Ballesteros-Duperón, M., & Lupiáñez, J. (2023). Attentional differences between gaze and arrows processing: where vs. what are eyes looking at. *Psicológica*, 44(2), 15274. https://doi.org/10.20350/digitalCSIC/15274

Abstract

A gaze is a complex stimulus that provides valuable social information during human interactions. It shares the ability to orient attention with other directional stimuli, such as arrows, but, still, gaze generates unique effects. A clear example was found using a spatial interference task (Cañadas & Lupiáñez, 2012; Marotta et al., 2018). Participants had to identify the direction—left or right—indicated by arrows or eyes located either on the right or left side. Arrows, like other nonsocial stimuli, elicited a standard congruency effect with faster responses to congruent location-direction trials than to incongruent ones. In contrast, gaze produced a reversed effect with faster responses to incongruent than to congruent trials. Socio-cognitive components of gaze processing could underlie this dissociation. Similar to a joint attention episode in everyday life, gaze would direct attention to a potentially relevant item. In congruent trials (i.e., left-located eyes looking to the left), gaze would orient attention outward, causing a slower response compared to incongruent trials where gaze would look to the central fixation point. With this study, we aimed at better understanding the underlying mechanisms of the reversed congruency effect of gaze by modifying the task—adding a bicolor frame—and its instructions. One group of 25 adults performed the task by identifying stimuli direction, as in previous studies. Another group of 25 participants had to identify the color to which stimuli were directed. We expected to find analogous congruency effects for arrows and gaze in the latter group since both stimuli would direct attention to color and held at this location, preventing gaze from seeking a potential attentional target during congruent trials. Although we found a reduced gaze effect, overall results were similar in both groups so the manipulation of instructions did not have the anticipated effect. The limitations of the study and the need for further investigations were discussed.

Keywords: Eye-gaze, arrows, social attention, attentional orienting.

Introduction

Preferential attentional orientation to faces and particularly to eyes is present very early in life. Humans are especially sensitive to detecting gaze (Adams & Kleck, 2003) and orienting attention in that direction (Hietanen et al., 2016). This ability facilitates the processing of attended stimuli and is fundamental for the development of social communication (Shepherd, 2010). However, other directional nonsocial stimuli share similar attentional orienting properties, as in the case of arrows. When used as central cues, as in classical cueing paradigms (Posner, 1980), both types of stimuli equally facilitated target processing (Chacón-Candia et al., 2023). This does not rule out the possibility that gaze also triggers specific mechanisms, but to dissociate them from the shared ones requires using paradigms that capture not only quantitative but qualitatively attentional differences. For instance, Marotta and colleagues (2012) used a modified version of a cueing task in which targets appeared inside one of two rectangles. The authors distinguished two types of attentional selection mechanisms depending on which stimulus was used as a central cue. Arrows facilitated the detection of any target that appeared within the indicated rectangle, both at the cued and the opposite ends. This spreading of attention did not occur with gaze, which facilitated the processing of targets appearing at the exact cued location within the cued rectangle. This difference could be related to the social meaning of gaze indicating the specific focus of interest of another person, thus restricting attention from scattering across the rectangle.

An even more clear dissociation has been found using a spatial interference task (Cañadas & Lupiáñez, 2012; Marotta et al., 2018) where participants have to identify the direction of social and nonsocial targets which could appear either on the left or right side of a central fixation point. The direction could be congruent with the location of the stimulus (i.e., a left-located arrow pointing to the left) or incongruent (a left-located arrow pointing to the right). Results showed opposite congruency effects for each type of target. Nonsocial stimuli, such as arrows or triangles, produced the standard spatial congruency effect (Lu & Proctor, 1995) with faster and more precise responses to congruent trials, where location and direction matched, than to incongruent ones. Surprisingly, gaze showed a reversed congruency effect as participants responded faster to incongruent than congruent trials. This gaze-specific reversed congruency effect could be capturing attentional factors linked to social interaction.

Indeed, further studies with the spatial interference task have not only replicated the results but also shown that the reversed congruency effect observed with gaze does not appear until adolescence, in contrast with standard attentional orienting to gaze, which is present from very early in development (Aranda-Martín, Ballesteros-Duperón & Lupiáñez, 2022). Furthermore, the emotional expression of the face can modulate the reversed congruency effect (Jones, 2015; Torres-Marín, et al., 2017) and this emotional modulation is not observed in participants with high levels of autistic traits, reinforcing the explanation of the effect in terms of social interaction (Marotta et al., 2022).

The reversed congruency effect seems to be robust and there are hints about an underlying social-based mechanism. However, its exact nature remains unclear. One of the first proposed explanatory hypotheses has to do with eye contact that would only occur in incongruent trials (note that, for example, a pair of right-located eyes looking to the left are looking to the central fixation cross where the participant is also looking). Conversely, in a congruent trial (i.e., two eyes on the right looking to the right) eyes would look outwards (Cañadas & Lupiáñez, 2012). A direct gaze is detected faster than an averted one (Conty et al., 2016), so eye contact could explain the facilitation that occurs for the gaze's incongruent trials, i.e., the reverse congruency effect. This hypothesis has been tested using the same task but responding to a non-spatial category: the color of the pupil (Narganes-Pineda et al., 2022). Color identification should also be affected by the putative eye contact of incongruent trials, but, as no reversion was found, the eye contact was dismissed as an explanatory hypothesis.

Given the role of gaze in inferring the interests, intentions, and behaviors of others, other hypotheses highlighted the influence of underlying mentalistic processes. For instance, in the aforementioned study by Marotta et al. (2012), the specific location-based effect of gaze could be a sign of its ability to pinpoint the focus of interest of a social partner. The reversed congruency effect could have a similar explanation. During incongruent trials (i.e., a pair of right-located eyes looking to the left) gaze is directed to the center, that is, to the fixation point. This "joint attention" could facilitate direction identification (Edwards et al., 2020). In contrast, gaze is directed outward in congruent conditions (i.e., two right-located eyes looking to the right). Gaze might automatically trigger the selection of the looked-at object. As there is no specific item to complete the attentional selection act, the identification of the direction could take longer as participants would automatically try to locate the object being looked at, leading to a distraction and ultimately resulting in a reversed congruency effect.

Together, all these data suggest that spatial and attentional orienting effects common to other directional stimuli, such as arrows, converge with unique social mechanisms in the processing of gaze direction. This study aims to delve into the nature of the reversed congruency effect manipulating how gaze is encoded by adding an external color frame and modifying task instructions. Despite performing the same task, participants could be instructed to respond according to directionality (where the stimulus is directed) or to an external item (what the stimulus is directed at). On the one hand, we expected to replicate the standard congruency effect of arrows—faster and more accurate responses on congruent than incongruent trials—and the reversed effect of gaze— faster and more accurate responses on incongruent than congruent trials—in the group of participants responding to the direction (hereafter Direction group). On the other hand, in the group responding to the color of the frame (hereafter Color group), the putative process underlying the reversed congruency effect, i.e., the search for an object automatically triggered only by gaze represented by an increased RT on congruent trials, would be overridden by the common needs of both arrows and gaze: to indicate the color. Therefore, by equalizing the processing requirements for both types of stimuli, we would only measure the similarities between arrows and gaze, so that, both would elicit a standard congruency effect. These hypotheses, as well as the method and analysis plan, were pre-registered before data analysis (https://osf.io/n7y36/).

Methods

Participants

We invited 50 undergraduate students (43 females) from the University of Granada, to participate in the study in exchange for academic credits (*M* = 21 years; *SD* = 2.5). A normal or corrected-to-normal vision was required to perform the task. They were randomly assigned to one of the two groups, Direction or Color, with 25 participants each. The sample size was chosen based on the experiment conducted by Cañadas and Lupiáñez (2012)—where the reversed congruency effect was described for the first time—with each experimental group consisting of a minimum of 22 participants. We considered the possibility of increasing data collection in case we would not achieve a Bayes factor providing evidence in favor of either the null or the alternative hypothesis, assuming a maximum number of 50 participants per group after which the experiment would be stopped in any case.

The study was performed under the ethical standards of the 1964 Declaration of Helsinki (last update: Seoul, 2008), as part of a larger research project, which has been positively evaluated by the University of Granada Ethical Committee (175/CEIH/2017).

Apparatus and stimuli

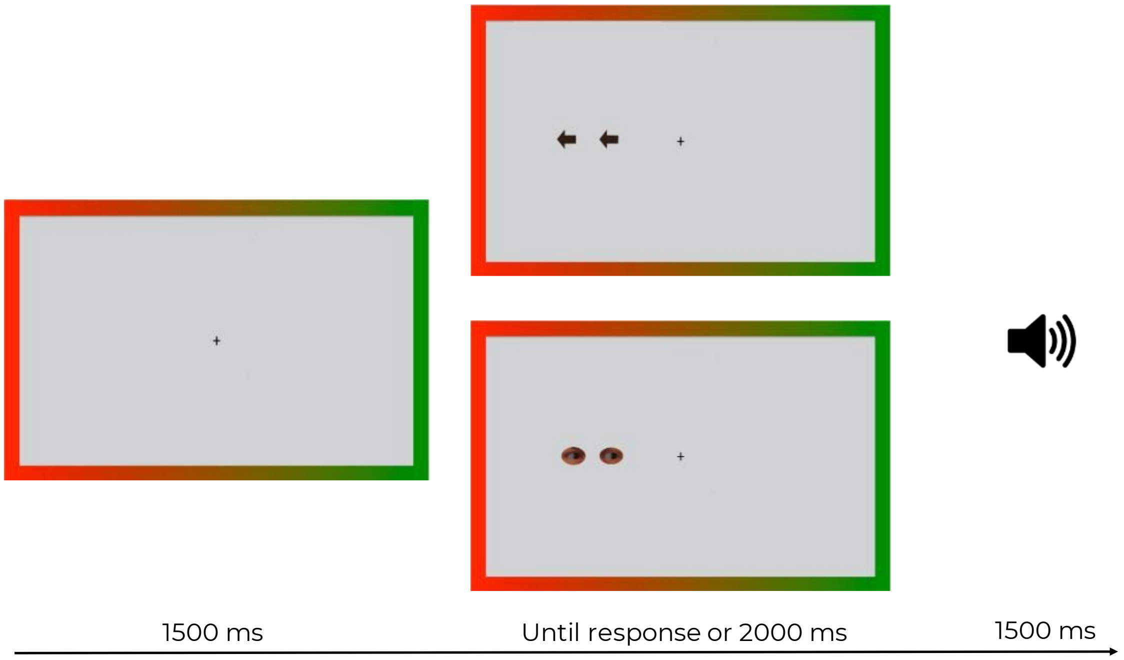
Stimulus presentation and data recording were controlled using the E-prime 2.0 software package and run on a standard Pentium PC with a 24” widescreen monitor with 1920 x 1080-pixel resolution. Stimuli were identical to those used by Marotta et al. (2018): two black arrows pointing to the right or left and two eyes looking either to the right or left. Eyes were obtained from a picture of a face from the MacBrain Face Stimulus Set[2]. Every stimulus was 6.5 x 1.5 cm and was presented on a grey background matching the screen. In this study, in addition to arrows and

[2] The face stimulus was obtained from the MacBrain Face Stimulus Set, developed by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. Please contact Nim Tottenham, at tott0006@tc.umn.edu, for more information concerning the stimulus set.

eyes, a bicolor frame was presented surrounding the screen in each trial. As shown in Figure 1, the frame was red on the left side, and it gradually changed to green on the right side.

Figure 1

Schematic Representation of a Trial Sequence with the two Stimuli and Congruency Conditions



Note. Arrows illustrate a congruent trial and eyes an incongruent one. The speaker icon represents the auditory feedback.

Procedure

We adapted the spatial interference task described previously (Cañadas and Lupiáñez, 2012; Marotta et al., 2018) by adding a green and red bicolor frame surrounding the display. Each trial started with a central fixation cross presented for 1500 ms. Participants were instructed to look at it during the entire task. Next, the corresponding stimulus (arrows or eyes) was presented at an eccentricity of 4.4°

of visual angle on the left or the right side of a central fixation cross. Task instructions were manipulated between groups. The Direction group received the same instructions as in previous studies (Cañadas & Lupiáñez, 2012; Marotta et al., 2018), i.e., to identify as quickly and accurately as possible the direction (right or left) to which the arrows were pointing or the eyes were looking at by pressing the corresponding key on the keyboard (m or z, respectively). The Color group, instead of responding to direction, had to respond to which color (red or green) the stimuli were looking at or pointing to. Although participants were not explicitly informed about the color position, each border had a fixed color. Since the left border was red and the right border was green, participants in both groups gave the same responses, e.g., by pressing the "z" key they responded to eyes looking to the left (Direction group) or the red color (Color group). After an incorrect response, a 220 Hz tone was presented for 1500 ms as feedback. The stimulus location on the screen was irrelevant but it creates two types of trials: congruent trials, when location and direction matched, and incongruent trials when they did not. For instance, a pair of right-located eyes looking to the right (green color) would be a congruent trial, but looking to the left would be an incongruent one. As in the study by Marotta et al. (2018), arrows and eyes were presented in two separated and counterbalanced blocks, each of them with 128 randomly selected trials (64 for each congruency condition). Both experimental blocks were preceded by 16 practice trials not included in the subsequent analyses.

Design

A mixed design was used with Congruency (congruent and incongruent) and Stimulus (arrows or eyes) as within-participants variables, and Group (Direction or Color) as between-participants. We performed a mixed ANOVA for each of the two dependent variables: reaction time (RT) and error percentage. In addition, we conducted a Bayesian repeated-measures ANOVA with the same variables.

According to our hypothesis, we expected to find a significant three-way interaction. In the Direction group, we expected to find a standard congruency effect responding to arrows and a reversed effect responding to gaze. However, no Congruency x Stimulus interaction was expected in the Color group. Although we believe that both dependent variables will behave similarly, we predicted these results primarily with the RT since it is a more sensitive measure than error percentage, especially in such an easy task.

Results

Practice trials were excluded from analyses. For reaction time, neither incorrect responses (3% of trials) nor responses faster than 200 ms (0.05%) or slower than 1300 ms (0.33%) were included in the analysis. Descriptive statistical data for both dependent variables, mean and standard deviation, are displayed in Table 1.

Table 1

Mean Reaction Time (RT) and Percentage of Errors and Their Corresponding Standard Deviation (SD)

		Arrows		**Gaze**	
		Congruent	**Incongruent**	**Congruent**	**Incongruent**
Direction	RT	476 (58.3)	514 (63.11)	572 (68.68)	564 (58.04)
	% errors	0.57 (0.9)	2.96 (2.74)	1.5 (1.94)	3.13 (3.06)
Color	RT	439 (54.53)	476 (56.19)	526 (61.69)	515 (56.21)
	% errors	1.88 (2.39)	4.94 (4.44)	4.07 (5.18)	5.02 (4.90)

Reaction Time

Similar to previous studies (Cañadas & Lupiáñez, 2012; Marotta et al., 2018), the analysis showed a significant effect of Stimulus, $F(1, 48)= 167.5$, $p < .001$, $\eta_p^2 = .78$, with slower RT responding to gaze than to arrows. Likewise, the main effect of Congruency was significant, $F(1, 48) = 20.22$, $p < .001$, $\eta_p^2 = .30$, with slower responses to incongruent compared to congruent trials. Critically, a significant Congruency x Stimulus interaction was found, $F(1, 48) = 87.5$. $p < .001$, $\eta_p^2 = .65$. Partial ANOVAs indicated that participants were significantly slower on incongruent than on congruent trials when responding to arrows, $F(1, 48) = 143.97$, $p < .001$, $\eta_p^2 = .75$. This difference was marginally significant with gaze, $F(1, 48) = 3.52$, $p = .067$, $\eta_p^2 = .07$, showing a reversed pattern of responses compared to arrows: slower responses on congruent trials than on incongruent ones.

Regarding Group, a significant main difference was observed, $F(1, 48) = 7.48$, $p = .009$, $\eta_p^2 = .14$, with higher RT in the Direction than in the Color Group, therefore indicating that participants were following instructions despite responding with the same mapping. Nevertheless, neither Stimulus x Group, $F(1, 48) = 1.03$, $p = .32$, $\eta_p^2 = .02$, nor Congruency x Group, $F(1, 48) < 1$, $p = .77$, $\eta_p^2 = .002$, nor the three-way interaction between Congruency, Stimulus and Group, $F(1,48) = .023$, $p = .88$, $\eta_p^2 = .0004$, were significant.

To analyze to what extent these data provide evidence about the presence or absence of these effects, a Bayesian analysis was carried out using a default prior of 0.63, not including the three-way interaction for which the prior was 0.05. Based on Wagenmakers et al., (2018), we performed the analysis by averaging each considered model, weighted by the posterior plausibility of that model given the data. The resulting Bayes Factor (BF) arises from the comparison of two possible models, one where the effect of interest is present and an identical one without that particular effect. The comparison is performed for each of the simple effects and interactions. Thus, we obtained the "BF inclusion" which indicates how likely is the model with the effect, assuming the default prior, based on the actual data collected. As shown in Table 2, BF showed extreme, strong, and moderate evidence (Wagenmakers et al., 2011) in favor of models with the simple effects of Stimulus, Congruency, and Group, respectively, compared to models without those effects. Both Stimulus and Stimulus x Congruency models received extreme support in favor. However, by adding the effect of Group to the interaction, the likelihood of the model is drastically reduced below 1. Thus, the BF provides moderate evidence for the absence of the three-way interaction (Stimulus x Congruency x Group), being

9.55 times more likely than its presence. Overall, the results suggest that the group did not affect the differential congruency effect of the two stimuli.

Table 2

Output for the Bayesian ANOVA of Reaction Time (in ms) and Error Rates

		RT (ms)		% errors	
Effects	P(incl)	P(incl|data)	BF(inclusion)	P(incl|data)	BF(inclusion)
Stimulus	0.263	6.287e -7	1.431e +30	0.400	2.775
Congruency	0.263	6.800e -7	26.120	0.566	6475.832
Group	0.263	0.485	5.808	0.520	3.333
Stimulus x Congruency	0.263	0.988	1.221e +6	0.326	0.621
Stimulus x Group	0.263	0.326	0.564	0.199	0.380
Congruency x Group	0.263	0.209	0.300	0.158	0.231
Stimulus x Congruency x Group	0.053	0.012	0.105	0.004	0.231

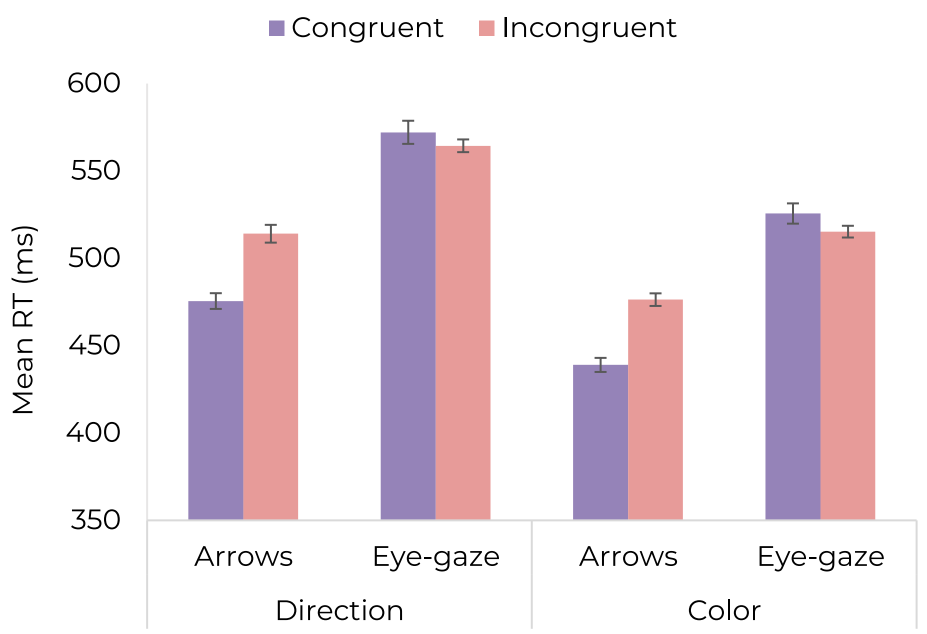
Note: P(incl.) refers to the summed prior probability of the models including the effects. After including data from the experiment, the posterior probability (P(incl./data) for each model is obtained. Finally, BF reports the change from prior to posterior inclusion probabilities, providing information on how plausible the model with the effect present is compared to the model without it.

Error Rate

We found a significant main effect of Stimuli, $F(1, 48) = 9.76$, $p = .003$, $\eta_p^2 = .17$, Congruency, $F(1, 48) = 15.6$, $p < .001$, $\eta_p^2 = .25$, and Group, $F(1, 48) = 6.3$, $p = .016$, $\eta_p^2 = .12$. Overall, participants committed more errors responding to gaze than to arrows, on incongruent than on congruent trials and, contrary to RT data, participants in the Color group committed more errors than those in the Direction group, demonstrating a trade-off between speed and accuracy. The Stimulus x Congruency interaction resulted marginally significant, $F(1,48) = 3$, $p = .09$, $\eta_p^2 = .06$, and it wasn't affected by Group as shown by a non-significant three-way interaction, $F(1,48) = 0.4$, $p = .55$, $\eta_p^2 = .008$. Both arrows, $F(1,48) = 22.7$, $p < .001$, $\eta_p^2 = .32$, and gaze, $F(1,48) = 3.99$, $p = .05$, $\eta_p^2 = .08$, showed a significant standard Congruency Effect. As shown in Table 2, the results of BF analysis were in line with frequentist analysis, yielding substantial to extreme evidence in favor of Congruency, Stimulus, and Group. However, and importantly, the BF yielded evidence in favor of the arrow's congruency effect, $BF_{incl} > 100$, but not the gaze one, $BF_{incl} = 1.2$. It should be noticed that the overall accuracy is near a ceiling effect ($M = 0.97$; $SD = 0.12$), so these results need to be interpreted with caution. Consistent with previous studies using the spatial interference task (Ishikawa et al., 2022), accuracy might not be a sufficiently sensitive measure given the ease of the task.

Figure 2

Graphic Representation of Mean Reaction Time (RT) in ms for the two Groups (Direction and Color)



Note. Errors bars indicate the standard error calculated by Cousineau Method (2005) to eliminate inter-participant variability

Discussion

This study aims to delve into the qualitative differences in the attentional processing of social and nonsocial directional stimuli, more specifically between gaze and arrows. Both types of stimuli share some attentional qualities, i.e., they have a similar capacity to orient attention in the indicated direction (Chacón-Candia, et al., 2023). Nevertheless, they also generate distinct attentional effects found with certain experimental paradigms. For instance, in spatial interference tasks, nonsocial stimuli, such as arrows, induce the well-known congruency effect, consisting of faster and more accurate responses when the pointed direction matches the stimulus's location (i.e., congruent trials, such as left-pointing arrows on the left side of the screen) compared when they do not match (i.e., incongruent trials, such as left-pointing arrows on the right side of the screen). Despite the robustness of this congruency effect, Cañadas and Lupiáñez (2012) found a surprisingly reversed congruency effect—which has been consistently replicated (Hemmerich et al., 2022; Marotta et al., 2018; Narganes-Pineda et al., 2022; Román-Caballero et al., 2021)—when the directional stimulus was an eye gaze: participants were faster and more accurate responding to incongruent than to congruent trials. This gaze-specific effect could be reflecting an additional attentional quality possibly related to its social nature.

Seeking to better understand the mechanisms at the basis of the reversed congruency effect, we manipulated how participants encoded the stimuli during the spatial interference task. Based on the fact that gaze, through social experience, becomes an increasingly specific cue about the other's focus of interest, we hypothesize that it could not only orient attention towards a direction but also to a specific object that would be attentionally selected. Therefore, on congruent trials, gaze might orient attention away looking for a potential object to attend to. If this were the case, such a "distraction" and, hence, a cost in RT, could be prevented by placing an object to attend to and instructing participants to respond to it. Thus, we would not expect to find the gaze reversed effect in the conditions responding to objects. To this end, we slightly modified the experimental task by adding a colored frame, so that one group of participants (Direction group) responded to the direction indicated by eyes or arrows and another group (Color group) responded to the indicated color. We expected that the gaze's reversed effect would only be found in the Direction group while in the Color group, both gaze and arrows would produce a standard congruency effect.

The results of this study replicate two effects reported in the literature. On the one hand, reaction times were longer in response to gaze than to arrows. As argued in previous studies (Hietanen et al. 2006; Marotta et al. 2018, Vlamings et al., 2005), the gaze would require a longer processing time compared to arrows due to its social burden and perceptual complexity. It should be noticed that some authors have nevertheless found the opposite pattern, i.e., an overall longer response time for arrows than for gaze cues, using tasks based on the cueing paradigm (Dalmaso et al., 2020a; Quadflieg et al., 2004). The diversity in experimental designs presents challenges in finding a single answer for variations in reaction time. However, recent meta-analytic results have identified moderating variables, such as the presence or absence of a direct gaze before an averted one, that could explain some of the observed variability in reaction time (Mckay et al., 2021). On the other hand, we found both a standard congruency effect responding to arrows and a reversed congruency effect responding to gaze, albeit with only marginal significance. However, the effect of gaze was not modulated by instructions, and a similar effect was observed regardless of whether participants responded indicating the direction of gaze or the color looked at. Thus, although finding the gaze's reversed effect is a relevant finding per se, since it replicates the double dissociation found in previous studies (Cañadas and Lupiáñez. 2012; Marotta et al., 2018), the results do not support the initial hypothesis of the study.

A possible explanation for the lack of differences might be linked to the experimental design of the task. Given that the location of colors was fixed (green on the right and red on the left), participants could have automatized their response by responding to direction and ignoring colors. For instance, when eyes looked at green, they were also looking to the right and the correct answer key would be "m" in both situations. Despite having different instructions, both groups would be performing the same task and, therefore, as we observed in the results, very similar effects would be obtained. Nevertheless, no group effect should have been observed in this case. The fact that participants were faster responding in the Color than in the Direction group suggests that they followed instructions. However, this difference might be due to other processes rather than responding to the location the gaze was looking at. This problem could be solved in future research by modifying the task so that the color could appear randomly and with equal probability on both sides of the screen. Consequently, since the position of the color would not always match the response key for direction, participants should attend to the color on each trial to respond correctly. This variation would add complexity to the task because of the response mapping. For instance, in trials where the green color appeared on the left, participants should respond by pressing the right-located key (“m”). This manipulation would add a new level of congruency between the response hand and the color, which could be ipsilateral or contralateral (note that this variable was irrelevant in our study as all trials were ipsilateral). Nevertheless, recent data showed no significant effects of this variable (Narganes-Pineda, et al., 2022), being a feasible modification to consider in future research. Furthermore, using pictures of real objects instead of colors would be another interesting modification of the task. In a social communication scenario where gaze would play a fundamental role, as in a joint attention episode, gaze would probably be directed at a particular object, person, or situation, but rarely at a color. While using colors may be the simplest option and can make the task easy even for children with diverse socio-cognitive abilities, using objects may be a more optimal approach if the reversed congruency effect actually describes a gaze-specific social component, providing a more accurate representation of real-life situations.

Further research is needed to fully understand the mechanisms underlying the reversed congruency effect. Gaze seems to produce additional attentional effects beyond the attentional orientation that shares with other directional and nonsocial stimuli, such as arrows. This qualitative dissociation between the two stimuli supports the idea that gaze processing involves not just general attentional mechanisms, but also social cognition processes (Marotta et al., 2018). These aspects are key in human development, especially in developmental disorders in which social cognition becomes essential for diagnosis, prognosis, and intervention. For instance, preferential attentional orientation, gaze processing, and joint attention are core features in autism spectrum disorders (Bruinsma et al., 2004; Franchini, Glaser, Gentaz, et al., 2017; Shultz et al., 2018). Increasing our understanding of the attentional characteristics of social stimuli and the behavioral and brain mechanisms underlying gaze processing could provide insight into typical and atypical development.

2 Study II

The role of object perception in attention triggered by gaze and arrows: Testing the joint distraction hypothesis

This study is in preparation as:

Aranda-Martín, B. Ballesteros-Duperón, M.A., Jiménez, L. and Lupiáñez, J. (2023). The role of object perception in attention triggered by gaze and arrows: testing the joint distraction hypothesis

Abstract

The attentional mechanisms elicited by arrows and gaze involve overlapping processes yielding similar behavioral outcomes. However, gaze produces unique effects possibly linked to social components. This dissociation is observed in a spatial interference paradigm where participants discriminate the direction of a laterally presented target (arrow or gaze) while disregarding its location. Both arrows and gaze generate a direction-location interference; however, while arrows show a standard congruency effect with slower responses to incongruent location-direction conditions than to congruent ones, gaze produces a reversed congruency effect (RCE), resulting in slower responses to congruent than incongruent conditions. The cause of the RCE is uncertain but may be attributed to a *joint distraction* process, define as an attentional drive to find the potential gazed-at object. The search for the object to be selected may slow down responses in congruent trials where gaze directs attention outward. To test this hypothesis, we introduced objects on each side to override joint distraction. The attentional process initiated by gaze would be completed on the gazed-at objects, preventing distraction and, hence, the RCE. Our findings did not confirm the joint distraction hypothesis, as the presence of objects did not affect the congruency effect of either gaze or arrows. We argue that the attentional selection following gaze direction may enhance object processing. To fully capture the impact of joint distraction, tasks measuring further object processing may be necessary. Future research using this paradigm can delve deeper into the interplay between gaze direction and object processing, particularly when compared to nonsocial stimuli.

Keywords: social attention, gaze, arrow, attentional orienting, spatial interference

Introduction

The eyes are a fundamental signal for human social cognition, allowing us to infer the thoughts, intentions, and behaviors of others (Baron-cohen, 2005; Tomasello et al., 2005). The particular characteristics of human eyes—such as the ratio between the white sclera and the dark iris (Kano et al., 2022; Kobayashi & Kohshima, 2001)—facilitate using eyes as an attentional cue even with an underdeveloped visual system such as that of newborns (Shultz et al., 2018). From days (Simion et al., 1998) or even minutes after birth (Goren et al., 1975), newborns already prefer to attend to face-like patterns and, more specifically, to eyes, preferring to look at faces with a direct rather than averted gaze (Farroni et al., 2002). These findings highlight the importance of the eyes as an attentional cue, being arguable that gaze must produce unique attentional effects.

Over the years, numerous studies have been conducted to compare the effect of gaze with other nonsocial stimuli, such as arrows, to understand how gaze uniquely impacts attention. However, recent meta-analytic results (Chacón-Candia, Román-Caballero, et al., 2023) found no quantitative differences in attentional orienting between arrow and gaze. With standard gaze or arrow cueing paradigms, both stimuli elicit a similar shift of attention in the indicated direction, resulting in a facilitation of responses to cued targets compared to uncued ones (i.e., the cueing effect). Still, some gaze-specific effects have been found using paradigms that focus on qualitative instead of quantitative differences. Perhaps the clearest example of that is the spatial interference paradigm (Cañadas & Lupiáñez, 2012), where participants identify the left or right direction of a lateralized stimulus that either matches (congruent trials) or mismatches (incongruent trials) the irrelevant stimulus location. The location-direction interference typically produces a standard Congruency Effect (Kornblum et al., 1990), with participants being slower responding to incongruent compared to congruent trials.

This spatial Congruency Effect has been found with arrows, words, and many other nonsocial stimuli (Liao & Wang, 2015; Lu & Proctor, 1995; Virzi & Egeth, 1985). However, and importantly, when gaze direction is used as the target, the opposite effect, namely, a Reversed Congruency Effect (RCE), has been observed (Cañadas &

Lupiáñez, 2012). This phenomenon has been widely replicated with different variations: cropped eyes (Marotta et al., 2018), faces with neutral (Aranda-Martín et al., 2022; Cañadas & Lupiáñez, 2012) or emotional expressions (Jones, 2015; Marotta et al., 2022; Torres-Marín et al., 2017), inverted faces (Tanaka et al., 2022), and diverse stimulus presentations (see Marotta et. al., 2018, for a between- block manipulation, and Narganes-Pineda et. al., 2022, for a within- block one). Although there were no quantitative differences between gaze and arrows in terms of initial directionality encoding and attentional orienting, gaze may contribute to mentalizing and shared attention processes. The gaze-specific RCE might be capturing this unique contribution.

The coexistence of shared and dissociable components in the observed effect of gaze has been supported by different findings, such as those obtained on *congruency sequence effects*, where the congruency effect observed in the current trial is reduced after an incongruent trial compared to a congruent one. This phenomenon, described for the first time by Gratton et al (1992), outline conflict adaptation showing that previous experience with conflict could facilitate its subsequent resolution. Importantly, these sequential effects are conflict-specific, so that, the benefit in performance only occurs when the conflict to be solved is of the same nature as the one previously experienced (Braem et al., 2014; Funes et al., 2010). Recently, Hemmerich et al. (2022) have tested the congruency sequence effects of the spatial interference task with arrows and gaze stimuli. Their findings revealed that both stimuli induce a similar conflict as both were influenced by previous conflict (the congruency condition in the previous trial) irrespective of the social or nonsocial nature of the preceding stimulus. Moreover, and critically, their results illustrated the diverging nature of each stimulus. Facing an incongruent trial, regardless of whether it was with an arrow or gaze target, reduced the standard congruency effect of a subsequent arrow trial, but increased the reversed effect of a subsequent gaze trial. This suggests that prior experience of conflict experienced with incongruent gaze or arrows reduced the spatial interference that affected both arrow and gaze stimuli similarly, but did not affect the unique and opposing effect of gaze. Further evidence in this line comes from event-related potentials (ERPs) elicited by arrows and gaze during the spatial interference task. Marotta et al. (2019)

found that gaze and arrows targets generated an identical congruency effect on early ERPs components (i.e., P1 and N1) but opposite effects on late ones (i.e., P3 and N2), suggesting that two distinct and coexisting factors may contribute to the observed effects. The first factor would be a shared spatial interference component that could account for the sequential effects between the two stimuli. The second factor would be a social gaze component, which may explain the occurrence of the RCE.

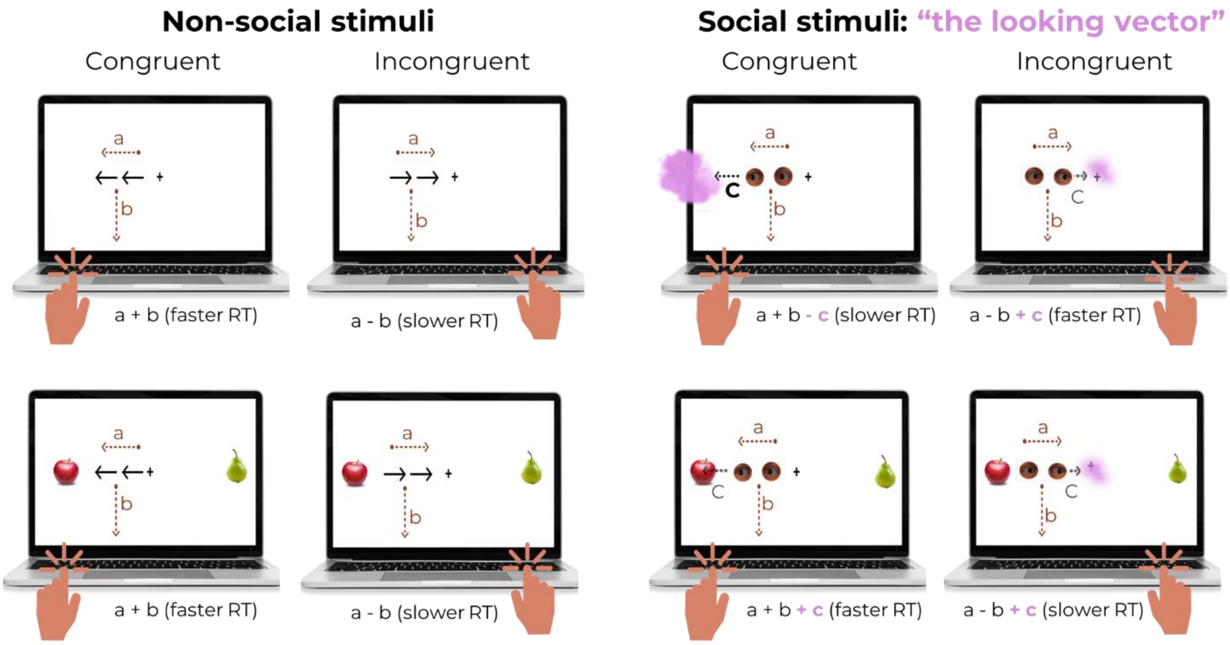
But what is the nature of this gaze-specific factor? What would gaze add beyond attentional orienting? Although there is no consensus at the moment, an inherent social interpretation of eye gaze could underlie the dissociation. Some data have shown that emotions (Jones, 2015; Marotta et al., 2022) and some individuals traits such as gelotophobia (Torres-Marín et al., 2017), anxiety (Ishikawa et al., 2021), or autistic traits (Marotta et al., 2022) could modulate the magnitude of the RCE or its interaction with emotions. Particularly, the RCE could be linked to the ability of eye direction to convey intentionality. From birth, humans learn to interpret gaze as a signal that indicates the object of interest of a social partner, rather than just signaling a direction in space as other nonsocial cues might do (Stephenson et al., 2021). This ability is evident as early as four months of age. Using a cueing task, Wahl et al. (2013) found that 4-month-old babies showed enhanced processing of gazed-at objects compared to non-gazed-at ones, as indicated by both looking times and brain electrophysiological responses. In contrast, nonsocial cues did not influence object processing, further underscoring the crucial role of gaze in facilitating object exploration in early infancy. A similar dissociation has been observed among adult individuals (Chacón-Candia, Lupiáñez, et al., 2023; Marotta et al., 2012). For instance, Marotta et al. (2012) used a version of a cueing task with gaze and arrows as central non-predictive cues in which targets could appear at either end of two tilted rectangles. Consistent with the aforementioned metanalytic findings (Chacón-Candia, Román-Caballero, et al., 2023), both arrows and gaze equally facilitated the detection of cued targets, when they were presented at the looked-at or arrow-indicated location, resulting in an identical cueing effect for the two stimuli. However, in the case of arrows, but not with gaze, this facilitation extended to targets appearing at the opposite end of the cued rectangle. While arrows seem to spread attention across the indicated object, gaze only facilitated the detection of targets situated at the specific location being gazed at.

This location's specificity of gaze cues resembles what happens during episodes of joint attention when two individuals share the same attentional focus. In fact, a joint attention hypothesis could be drawn from the RCE. During incongruent trials (e.g., two left-located eyes looking to the right, i.e., to the center of the screen) gaze could lead participants to "jointly" look at the fixation point, thus enhancing direction identification (Edwards et al., 2020). However, even though joint attention skills are fully developed in early childhood, it has been shown that the RCE is not present in children under the age of 12 (Aranda-Martín et al., 2022).

Another explanation could be related to congruent trials when the eyes look outwards. As depicted in Figure 1, both gaze and arrows can trigger similar orienting effects towards the pointed or gazed direction (represented by "a") together with the spatial activation of their location (represented by "b"). These two opposite forces would lead to the location-direction interference shown by both social and nonsocial directional stimuli. Nevertheless, coping with eyes during everyday social interactions may entail specialized mechanisms of incidental attentional search and selection of potentially socially relevant (i.e., looked at) objects (represented by "c"). Even when there is nothing relevant to look at—as during congruent trials where the eyes look outwards—gaze may still trigger this default mechanism, resulting in a "joint distraction" that slows down direction identification and contributes to the final RCE (Hemmerich et al., 2022). Evidence of the link between gaze direction and object selection has been observed at the neural level. In contrast to arrows or non-directed eye movements, the neural response associated with gaze direction seemed to be modulated by whether it was directed towards an object or empty space (Hooker et al., 2003; Materna et al., 2008; Pelphrey et al., 2003). Notably, this distinctive gaze activation was not observed in individuals with Autism Spectrum Disorder which is characterized by impairments in social cognition (Pelphrey et al., 2005). All of this data illustrates how gaze processing is influenced by the intrinsic assumptions that gaze indicates intentionality and, therefore, the act of looking is aimed towards a specific item of presumed interest.

Figure 1

Visual Representation of the Proposed Model of Shared and Unique Effects of Social and Nonsocial Stimuli During the Spatial Interference Task Based on the Presence or Absence of Objects



Note.: Adapted from Hemmerich et al., 2022. This picture illustrates the hypothetical vectors (represented by the letters a to c) that would come into play during the spatial interference task using arrows (left half) or gaze targets (right half) and depending on the absence (upper half) or presence (bottom half) of objects. Two vectors represent the common processes for arrows and gaze: the shift in attention caused by direction encoding (a) and the spatial activation of the location (b). The presumed gaze-specific "looking vector" is represented by "C" and the purple trail characterizes the incidental attentional search for the selection of gazed objects. Note that the purple trail (C vector) triggers joint attention on incongruent trials, but draws attention outside the display on congruent trials, hypothetically leading to so-called joint distraction. The presence of objects on each side (in the bottom panel) should reduce or eliminate joint distraction. For illustrative purposes, the stimuli are not reproduced to full scale being larger in the figure than in the real task.

Based on the idea that gaze triggers both common directional attentional processes and additional social ones, we wanted to investigate whether joint distraction accounts for the unique contribution of gaze. To achieve this, we added objects to the spatial interference task in an attempt to prevent joint distraction. As long as the gaze would be looking at those objects, the attentional act would be fulfilled, thus equating orienting by arrows and gaze and overriding any presumed distraction on incongruent trials specific to gaze. After eliminating joint distraction, gaze would still generate a location-direction interference, as evidenced by a standard congruency effect. In contrast, we expected that the presence of objects would not affect the effect observed with arrows. Thus, we expected the usual standard congruency effect for arrows and reversed for gaze without objects, and standard congruency for both arrows and gaze when joint distraction was eliminated by the presence of objects.

Experiment 1: Trial-By-Trial Manipulation of Objects

In this experiment, we investigate whether the inclusion of objects in the spatial interference task could prevent joint distraction and eliminate the reversed congruency effect (RCE) of gaze. We used a slightly modified version of the task in which objects were added at the end of the two possibly cued locations, with the presence or absence of objects manipulated on a trial-by-trial basis (see Figure 2), willing to capture a powerful enough dissociation that could be observed trial-by-trial. On the one hand, we expected to replicate the RCE of gaze observed in prior studies in trials with no objects. On the other hand, we predicted that the inclusion of objects would prevent joint distraction, and consequently, eliminate the RCE. However, the processes shared with arrows would not be affected by objects, therefore leading to a standard congruency effect with gaze when objects are presented.

Method

Participants

We invited 30 undergraduate students from the University of Granada to take part in the experiment in exchange for academic credits. The sample size was based on an a priori power analysis conducted by the software GPower 3.1 (Erdfelder et al., 2007). Assuming a small effect size of $\eta_p^2 = .11$ for the RCE, which was derived from previous experiments (Aranda-Martín et al., 2022b, 2023), setting the significance level at 0.5 and a power of 0.9, the required sample size was 29. The sample characteristics of all experiments included in this paper were summarized in Table 1.

Participants provided their informed consent and were aware of their right to withdraw from the experiment at any time. All participants reported having normal or corrected to normal vision and were naive about the purpose of the experiment. These conditions were required in this and the following experiments.

Table 1

Sample Descriptive From Experiments 1 to 4.

	Group	*N* (female:male)	Mean (*SD*) age in years
Exp 1	Direction	28 (22:6)	20.4 (1.97)
Exp 2	Direction	30 (17:13)	24 (5.85)
Exp 3	Direction	24 (22:2)	20.3 (2.03)
	Color	25 (20:5)	20 (1.54)
Exp 4	Direction	28 (23:5)	21.7 (5.11)
	Object	29 (24:5)	20.5 (2.29)

Apparatus and Stimuli

The experimental task was designed and run by using E-prime 2.0. Through this software, we controlled stimulus presentation, timing, and data collection. The experiment was conducted on a standard Pentium PC with a widescreen monitor of 24” with a 1920 x 1080-pixel resolution. Participants were seated at approximately 60 cm from the center of the screen in a well-lit room. Stimuli were identical to those used by Marotta et al. (2018): two black arrows and a pair of eyes, with a dimension of 1 x 4 cm, pointing or looking to either right or left. Eyes were obtained from a picture of a real face from the MacBrain Face Stimulus Set[3]. Stimuli were located at 4° eccentricity from the central fixation cross. We also used two real pictures of a pear and an apple of 2.5 x 2.5 cm that were obtained from Google images (apple from https://www.pngmart.com/es/image/65742, and pear from http://irisboafruta.com.br/es/productos/pera) and were displayed at 11° from the center. All images were presented on a grey background. We selected these specific items based on their shared semantic category, valence, and frequency. Also, both words were learned at early stages of vocabulary development, typically around 2 years of age (Fenson et al., 1994), making the task suitable for a wide range of ages and cognitive levels.

Procedure

We modified the Spatial Interference task (Marotta et al., 2018) by adding in half of the trials two photographs of real objects – a pear and an apple - on each side of the display. As represented in Figure 2, the procedure was similar to the Spatial Interference task used in prior studies (Cañadas & Lupiáñez, 2012; Marotta et al., 2018). Each trial started with a central fixation cross presented for 1500 ms at which participants were asked to look throughout the task. Next, the corresponding stimulus—a pair of arrows or eyes separated in two counterbalanced blocks—was

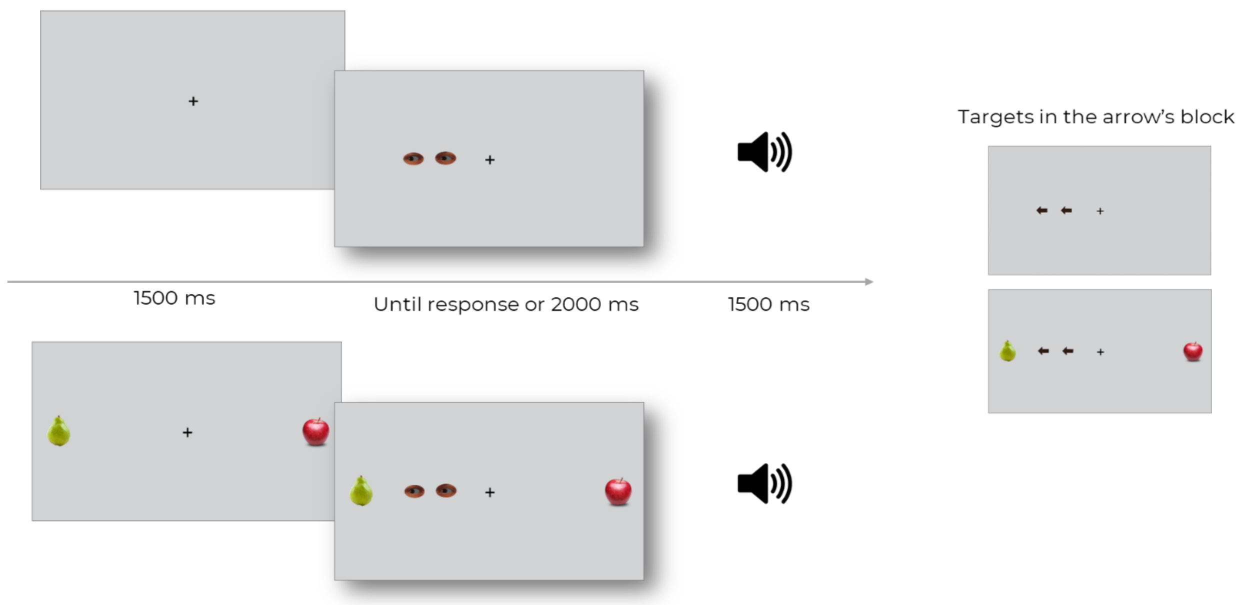
[3] Faces were obtained from the MacBrain Face Stimulus Set, developed by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. Please contact Nim Tottenham, at tott0006@tc.umn.edu, for more information concerning the stimulus set.

presented. Participants were instructed to identify as quickly and accurately as possible the direction of the stimuli by pressing “z” for left or “m” for right. No instructions were given regarding objects. The location —right or left— of gaze and arrows was irrelevant but it creates two types of trials: congruent trials when location and direction matched, i.e., a pair of right-located eyes looking to the right, and incongruent trials when they did not, i.e., a pair of right-located eyes looking to the left. After an incorrect response, a 220 Hz tone was presented for 1500 ms as feedback.

Objects were presented in half of the trials on a trial-by-trial basis creating two conditions: absence or presence of objects. In any case, they were completely irrelevant to the task at hand. It should be noticed that on trials with no object, participants performed an identical spatial interference task as in precedent studies (Marotta et al., 2018).

Figure 2

Schematic Representation of Procedure of Experiment 1



Note: This picture illustrates a congruent trial. The speaker icon represents the auditory feedback of incorrect responses. For illustrative purposes, the stimuli are not reproduced to full scale being larger in the figure than in the real task.

Design

In the preceding (Aranda-Martín et al., 2023) and following experiments (3 and 4), we preregistered to analyze data with a 2x2x3 design, with Congruency (Congruent and Incongruent), Stimulus (Gaze and Arrows) and Object (Objects, No Objects, Mixed) as within-participants factors. However, given recent findings based on the congruency sequence effect (Hemmerich et al., 2022), we decided to add to the design and analysis the variable Previous Trial (N-1) Congruency for completeness. Congruency and Object were manipulated within blocks, whereas Stimulus was presented in two counterbalanced blocks. Reaction times (RT; in ms) and error rates were used as dependent variables. Although error percentages were predicted to follow a similar pattern, these results were expected especially with RT which is a more sensitive measure for such an easy task.

Results

Two mixed ANOVAs were conducted, one for each dependent variable. In addition to frequentist analysis, we performed analogous Bayesian ANOVAs[4] to further confirm results. Outlier detection was based on performance (i.e., mean reaction times, RTs; and accuracy). For RT analyses, as in the precedent study of Marotta et. al., 2018, incorrect responses (2%) and trials faster than 200 ms (0.2%) or slower than 1300 ms (0.7%) were excluded, for being deemed anticipations and lapses respectively. Two participants were eliminated based on their overall accuracy, the criterion being set at two standard deviations below the group mean, resulting in a final sample of N = 28. The resulting mean RTs and error rates for this and subsequent experiments were shown in Table 2.

[4] Based on Wagenmakers et al., 2018, we performed the analysis by averaging all models considered. The resulting BF inclusion (BF_{incl}) arises from comparing the two possible models—a model with the effect present and an identical one without it— for both simple and interactive effects. Starting from a default prior of 0.5 for fixed effects and 1 for random effects, results estimate the plausibility of each model given the actual data.

Table 2

Mean Reaction Time (in ms) and Error Rates and Their Corresponding Standard Deviation (SD) From Experiments 1 to 4

				Gaze				Arrow			
			Dependant variable	Congruent N-1		Incongruent N-1		Congruent N-1		Incongruent N-1	
	Group	Items		Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent
Exp 1	Direction	No Objects	RT	548 (91.45)	567 (97.97)	584 (94.86)	552 (97.72)	468 (88.04)	520 (93.16)	487 (88.25)	506 (100.48)
			Error%	0.02 (0.05)	0.02 (0.04)	0.02 (0.03)	0.02 (0.04)	0.004 (0.02)	0.03 (0.04)	0.01 (0.03)	0.01 (0.03)
		Objects	RT	545 (92.44)	563 (99.66)	569 (98.89)	538 (87.84)	451 (77.07)	505 (87.35)	478.05 (87.51)	498 (89.34)
			Error%	0.01 (0.03)	0.03 (0.06)	0.02 (0.04)	0.02 (0.04)	0 (0)	0.03 (0.05)	0.02 (0.05)	0.02 (0.03)
Exp 2	Direction	No Object	RT	509 (55.69)	542 (67.34)	551 (62.73)	519 (74.69)	—	—	—	—
			Error%	0.003 (9.18)	0.04 (0.05)	0.013 (0.04)	0.007 (0.02)				
		Object	RT	500 (71.53)	529 (72.15)	536 (61.57)	514 (72.66)	—	—	—	—
			Error%	0.003 (0.02)	0.04 (0.06)	0.03 (0.05)	0.007 (0.03)				
		Mixed	RT	506 (59.14)	532 (67.37)	544 (70.86)	519 (71.17)	—	—	—	—
			Error%	0.003 (0.018)	0.03 (0.06)	0.01 (0.025)	0.01 (0.031)				
Exp 3	Direction	Color	RT	556 (86.55)	593 (94.24)	597 (88.84)	563 (98.52)	452 (66.37)	520 (79.61)	488 (85.63)	493 (69.17)
			Error%	0.001 (0.007)	0.05 (0.05)	0.02 (0.03)	0.01 (0.02)	0.001 (0.006)	0.04 (0.03)	0.02 (0.02)	0.02 (0.03)
	Color	Color	RT	734 (103.64)	760 (128.18)	755.28 (110.62)	763 (116.96)	648 (106.20)	700 (116.93)	662 (108.29)	703 (119.80)
			Error%	0.05 (0.05)	0.08 (0.06)	0.07 (0.07)	0.09 (0.08)	0.05 (0.05)	0.09 (0.07)	0.05 (0.05)	0.08 (0.08)
Exp 4	Direction	Objects	RT	521 (83.07)	556 (80.97)	570 (83.39)	540 (78.78)	428 (67.91)	499 (79.35)	465 (79.57)	480 (71.67)
			Error%	0.013 (0.03)	0.04 (0.04)	0.02 (0.04)	0.02 (0.03)	0.003 (0.02)	0.04 (0.04)	0.02 (0.03)	0.02 (0.04)
	Object	Objects	RT	713 (77.75)	749 (77.01)	736 (76.73)	742 (82.83)	653 (90.23)	701 (100.65)	666 (89.18)	715 (101.80)
			Error%	0.03 (0.02)	0.04 (0.04)	0.05 (0.04)	0.04 (0.05)	0.03 (0.04)	0.05 (0.04)	0.02 (0.02)	0.05 (0.05)

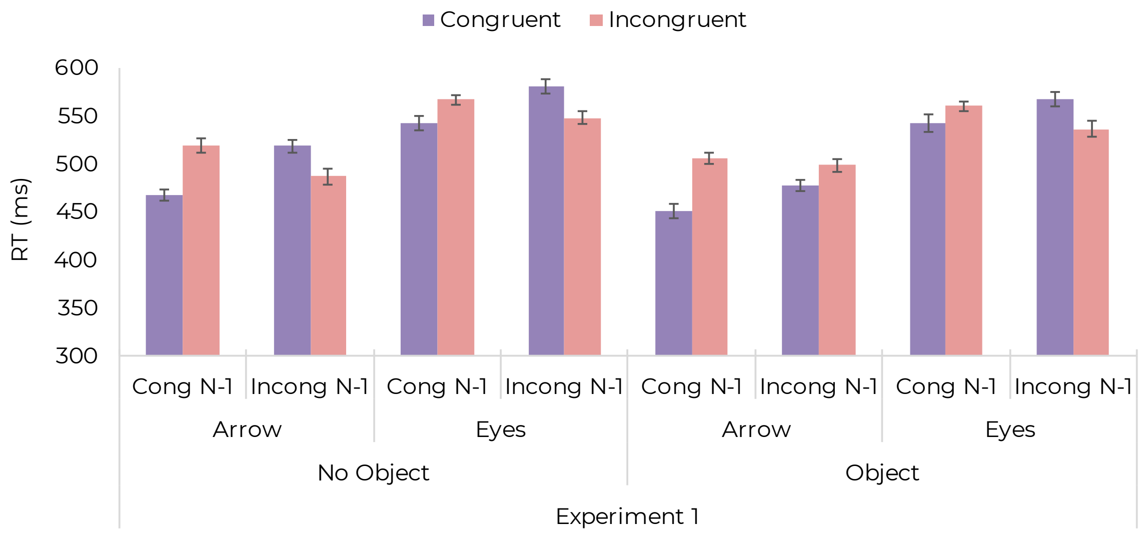
Reaction Time

The ANOVA performed on mean RTs revealed a significant effect of Stimuli, $F(1,27) = 80.62$, $p < .001$, $\eta_p^2 = .75$, $BF_{incl} = 2.8 \times 10^{54}$, Congruency, $F(1,27) = 14.28$, $p < .001$, $\eta_p^2 = .35$, $BF_{incl} = 141.16$, and Object Condition, $F(1,27) = 7.07$, $p = .013$, $\eta_p^2 = .21$, $BF_{incl} = 8.5$. Participants were slower responding to gaze than to arrows, to incongruent than to congruent trials, and to trials without objects than to those with objects. Stimulus and Congruency showed a significant interactive effect, $F(1,27) = 48.66$, $p < .001$, $\eta_p^2 = .64$, $BF_{incl} = 2.5 \times 10^4$, due to a standard congruency effect responding to arrows, $t(27) = 7.28$, $d = 0.39$, $p_{holm} < .001$, and no effect responding to gaze, $t(27) = 1.34$, $d = .07$, $p_{holm} = .19$. The expected Previous Congruency x Congruency interaction was significant, $F(1,27) = 56.25$, $p < .001$, $\eta_p^2 = .68$, $BF_{incl} = 2.45 \times 10^6$, and importantly, not modulated by Stimulus, $F(1,27) = 1.88$, $p = .18$, $\eta_p^2 = .07$, $BF_{incl} = 0.35$. Object Condition did not modulate either the congruency effect, $F(1,27) = .20$, $p = .88$, $\eta_p^2 = 7.4 \times 10^{-4}$, $BF_{incl} = 0.22$, or the Previous Congruency x Congruency interaction $F(1,27) = .010$, $p = .92$, $\eta_p^2 = 3.8 \times 10^{-4}$, $BF_{incl} = 0.2$. More importantly, and against our main hypothesis, the presence of objects did not modulate the Congruency x Stimulus interaction, $F(1,27) = .005$, $p = .95$, $\eta_p^2 = 1.82 \times 10^{-4}$, $BF_{incl} = 0.3$

Indeed, as can be observed in Figure 4, for both arrows and gaze the congruency effect was reduced or reversed after incongruent conditions. Following a congruent trial, arrows produced a standard congruency effect (53 ms, $t = 8.24$, $p_{holm} < .001$) that was reduced after an incongruent trial (19 ms, $t = 2.97$, $p_{holm} = .019$). Similarly, eyes yielded a standard effect after congruent trials (19 ms, t = 2.88, $p_{holm} = .019$) that was significantly reversed after incongruent trials (-32 ms, t = -4.94, $p_{holm} < .001$). Importantly, the same pattern was observed independently of the presence or absence of objects (Figure 4).

Figure 4

Mean Reaction Time (RT) for each Object Condition, Stimulus, Previous Trial (N-1) Congruency, and Congruency of Experiment 1



Note. Errors bars represent the standard error corrected with Cousineau's method (2005) to eliminate between-participant variability.

Error Rate

We found a marginal main effect of Congruency, $F(1,27) = 3.58$, $p = .07$, $\eta_p^2 = .12$, $BF_{incl} = 3.10$, participants committing more errors on incongruent than on congruent trials, and an interactive effect of Previous Congruency x Congruency, $F(1,27) = 3.94$, $p = .06$, $\eta_p^2 = 0.01$, $BF_{incl} = 1.88$. The congruency effect seems to be present after congruent trials (0.007, $t = 1.07$, $p_{holm} = .05$) and absent following incongruent conditions (0.001, $t = 0.20$, $p_{holm} = .87$).

Similar to previous studies using the spatial interference task (Ishikawa et al., 2022; Aranda-Martín, et al., 2023), it is important to approach the error data with caution due to the high overall accuracy ($M = 0.98$, $SD = 0.01$), which suggests the possibility of a ceiling effect.

Discussion

This experiment showed that the presence or absence of objects did not affect the congruency effect, neither the standard congruency effect observed for arrows nor the RCE observed for gaze. Although the reversion did not emerge as an overall effect, it was clearly observed after congruent trials, consistently with previous work (Hemmerich et al., 2022).

The most important finding, however, was that the presence of objects did not affect the RCE, which does not support the joint distraction hypothesis. Nonetheless, the random appearance of objects in some trials may hinder the detection of subtle effects by forcing participants to update the spatial configuration trial by trial. To avoid joint distraction, it may be necessary to present objects continuously for a longer period of consecutive trials. To address this issue, we compared the condition in which the RCE has been typically observed—consecutive trials with no background objects— with a similar condition designed to override it: consecutive trials with objects present. Additionally, we further test and replicate the influence of objects on a trial-by-trial basis by introducing a third block in which objects appeared randomly.

Experiment 2: Three Objects Blocks

Participants completed the spatial interference task in three counterbalanced blocks: a block in which objects were always present, another block with no objects, and a third block that alternated between the presence and absence of objects on a trial-by-trial basis. We hypothesized that the RCE would be observed in the No Object block, which would be reduced or even eliminated in the object block. Based on our preliminary findings, we expect the lack of RCE to be more prominent in the object block than in the mixed block, where we anticipated replicating the reversed effect observed in Experiment 1.

Method

Participants

A group of 32 undergraduate students performed the task in exchange for either academic credits or cash (5€). The sample size selection was based on Experiment 1, as similar interactive effects were expected. Inclusion and exclusion criteria were also the same as in the previous experiment.

Procedure

We used identical stimuli and devices to program and display the task as in Experiment 1. Each trial followed the same structure as in Experiment 1 (see Figure 2), but, since the effect of arrows is not influenced by objects nor is it expected to be, we only used gaze as target stimulus in this experiment. The task was presented in three counterbalanced object blocks. Half of the participants began with a No Object block. For half of those participants, the No Object block was followed by the Mixed block and then the Object block, while for the other half, the order was reversed. The other 50% of participants began with an object block (divided between Mixed or Object-only), followed by a No Object block.

Design

The experiment followed a 2 x 2 x 3 structure, with Previous Congruency (N-1 Congruent or N-1 Incongruent), Congruency (Congruent and Incongruent), and Block (Object, No Object, Mixed) as within-participants variables. Again, reaction times (RT; in ms) and error rates were used as dependent variables.

Results

Two participants were removed from the sample for having an accuracy rate two standard deviations below the group media. One of them seems to have misunderstood instructions and responded to the location of eyes instead of gaze direction, resulting in an average error rate of 0% for congruent conditions and 99% for incongruent ones. ANOVA was performed with a final sample of 30 participants.

Reaction Time

For RT analysis, the same filtering criteria as in the preceding experiment were used, excluding incorrect responses (4%), anticipations (0.2%) and lapses (0.3%).

The ANOVA showed a Previous Congruency x Congruency interaction, $F(1,29) = 154$, $p < .001$, $\eta_p^2 = .84$, $BF_{incl} = 4.6 \times 10^{22}$, which was not modulated by Block, $F(2,59) = 2.09$, $p = .13$, $BF_{incl} = 0.22$. The results showed the distinctive conflict adaptation of gaze: a congruency effect after a congruent trial (29 ms, $p_{holm} > .001$) that was reverted following the incongruent ones (-26 ms, $p_{holm} > .001$). Neither Congruency, $F(1,29) = 0.14$, $p = .71$, $\eta_p^2 = .005$, $BF_{incl} = 0.13$, nor the interaction of Congruency x Block, $F(2,29) = 0.32$, $p = .73$, $\eta_p^2 = .01$, $BF_{incl} = 0.8$, showed significant effects. Furthermore, a partial ANOVA within the Mixed Block comparing trials with or without objects, neither yielded a main effect of Objects, $F(1,29) = 3.23$, $p = .08$, $\eta_p^2 = .1$, $BF_{incl} = 0.65$, nor interactive effects, (Congruency x Objects, $F(1,29) = 0.27$, $p = .61$, $\eta_p^2 = .009$, $BF_{incl} = 0.24$; Previous Congruency x Congruency x Objects $F(1,29) = 1.16$, $p = .29$, $\eta_p^2 = .038$, $BF_{incl} = 0.35$), thus replicating the pattern observed in Experiment 1.

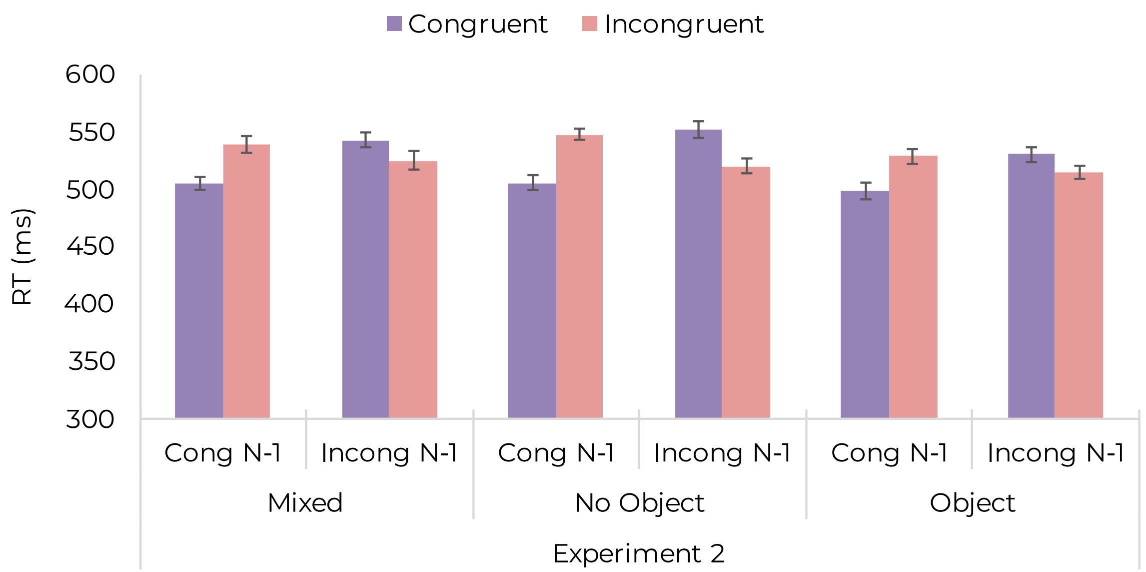
Error Rate

Similar to Experiment 1, we found a main Congruency effect, $F(1,30) = 5.86$, $p = .022$, $\eta_p^2 = .17$, $BF_{incl} = 9.19$, with participants committing more error on incongruent than congruent conditions, and an interactive effect of Previous Congruency and Congruency, $F(1,30) = 17.48$, $p < .001$, $\eta_p^2 = .38$, $BF_{incl} = 1.41 \times 10^5$. The congruency effect was present after congruent trials (0.033, $t = 4.67$, $p_{holm} < .001$) and disappeared after incongruent trials (0.009, $p = 0.44$).

Nevertheless, it is important to consider the possibility of a ceiling effect as the overall accuracy was particularly high (M = 0.96, SD = 0.14).

Figure 5

Mean Reaction Time (RT) for Each Object Condition, Previous Trial (N-1) Congruency and Congruency of Experiment 2



Note. Errors bars represent the standard error corrected with Cousineau's method (2005) to eliminate between-participant variability.

Discussion

Contrary to our initial prediction, the presence of objects did not influence the congruency effect of gaze, which remained consistent across all types of blocks. As observed in Figure 5, the emergence of a reversed pattern of congruency sequence effects, even in the Object block, both replicates the results of Experiment 1 and challenges the hypothesis of joint distraction.

Nevertheless, we reasoned that the mere perception of objects may not be enough to fully understand the impact of gaze, as its effects can extend to subsequent processing levels. For instance, research into joint attention has demonstrated that gaze plays a critical role in language development and object learning (Morales et al., 1998; Mundy & Newell, 2007) suggesting that gaze can have a lasting impact on processing. In Experiments 1 and 2, the objects were merely present, so no response or processing was required. However, the social dynamics of gaze and objects may trigger an additional layer of processing that requires more than just perceiving the objects, making necessary an active response to objects to override joint distraction.

A previous preregistered study (Aranda-Martín et al., 2023) has already tested this idea using a modified version of the task by adding colors on either side and dividing the participants into two groups. The Direction Group identified the direction of the target stimulus (either a pair of arrows or eyes) as usual, while the Color Group, instead of the direction of the target, identified the color the arrows were pointing to or the gaze was looking at by pressing the corresponding key. The color position was fixed, with green on the left and red on the right, to prevent any potential interplay between color location and response key in the Color group. The corresponding key for each color was on the same side, resulting in only ipsilateral responses, as in the classic spatial interference task without objects or colors on the sides. As in currently reported experiments, no between groups differences were observed. Both the group of participants who indicated arrows or gaze direction and the group indicating the pointed or looked-at color showed the same pattern of results, providing again no evidence in support of the joint distraction hypothesis. However, the fact that the same color was constantly presented on each side, so that responses were exactly the same in both groups, may have led participants to overlook the color, making it challenging to differentiate group effects. Both groups would give the same response, i.e., pressing "m" to answer "green" in the Color group or "right" in the Direction group.

In the following pre-registered experiment ([osf.io/3h2ut](osf.io/3h2ut)), we modified the procedure described by Aranda-Martín et al (2023) by randomly changing the color position trial-by-trial. This way we ensure both the presence of an object and the selection of a response based on the object presented at the indicated or looked-at location.

Experiment 3: Color identification

According to the raised hypothesis by Aranda-Martín et al (2023) and the results obtained from Experiments 1 and 2, we expected to replicate an RCE in the Direction group and to find a standard effect in the Color group in response to gaze. For arrows, we predicted a standard congruency effect irrespective of group.

Method

Participants

We invited 52 undergraduate students to take part in the experiment in exchange for academic credits. They were randomly assigned to the Direction or the Color group. The preregistered sample size (N = 52) was based on the precedent study (Aranda-Martín, et al, 2023) for which sample size was a priori calculated.

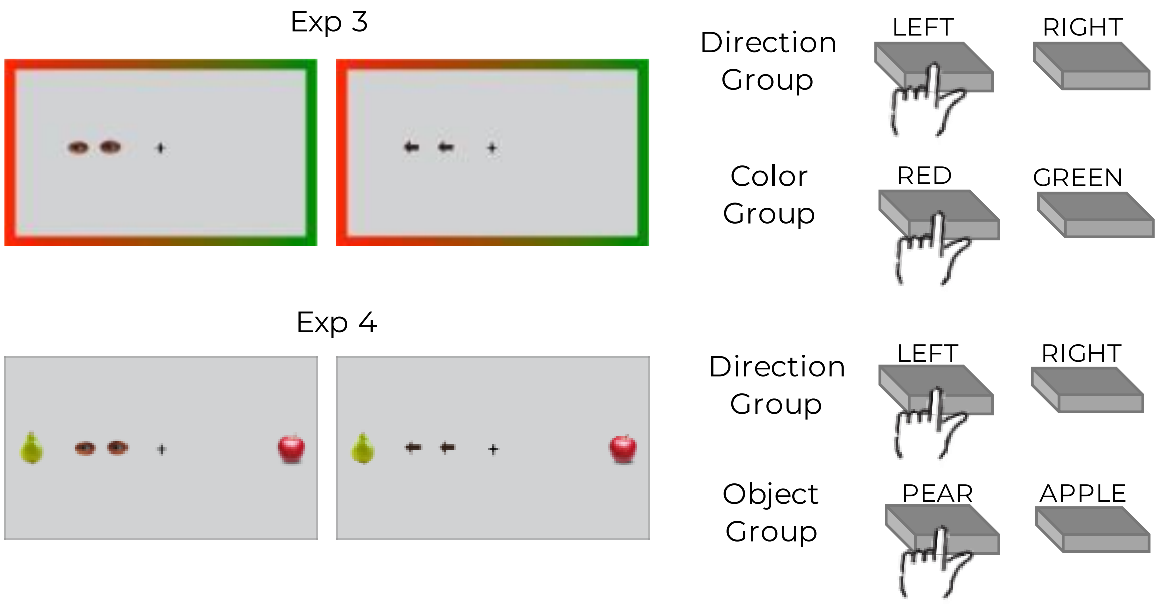
Procedure

We used the same stimuli and devices to program and present the task as in Experiments 1 and 2, except for the two-color frame which was the same as that used in Aranda-Martín et al. (2023).

The procedure was similar to Aranda-Martín et al. (2023), in which a color frame was displayed surrounding the central part of the screen (see Figure 6), green on one side and red on the other, but the position of the colors (right or left) was randomized on a trial-by-trial basis. The Direction group received the same instructions as in Experiments 1 and 2, identifying the direction of the stimuli by pressing “z” for left or “m” for right, as quickly and accurately as possible. In contrast, the Color group responded to the color (red or green) that the stimuli were pointing or looking at by pressing the same keys, but with “z” for red or “m” for green. To address the potential interference caused by the arbitrary response mapping, which could be accentuated by the direction of stimuli, a larger practice was provided to both groups. This involved an initial training block of 16 trials where a central stimulus, either a color (green or red) for the Color group or a word ("right" or "left") for the Direction group, was presented for 1500 ms. To further simplify the task, the keys had stickers matching the response: green and red stickers for the Color group and “D” and “I” stickers for the Direction group, symbolizing the Spanish words “derecha” (right) and “izquierda” (left). Afterward, all participants performed 24 further practice trials and two counterbalanced experimental blocks, one for each stimulus type. Each block had 128 trials, collecting 64 observations per experimental condition, and participants were allowed to rest halfway.

Figure 6

Schematic Representation of Targets and Required Responses of Experiments 3 and 4



Note. This picture illustrates the targets for a congruent trial and the corresponding responses for each group. For illustrative purposes, the stimuli are not reproduced to full scale being larger in the figure than in the real task.

This procedure was previously tested as a pilot experiment with 16 participants to make sure that the task worked properly and could be easily performed. Although participants in the Color group were 173 ms slower, they could complete it successfully (95% correct). Furthermore, a recent study has tested the influence of response laterality in this task (Narganes-Pineda et al., 2022), finding that although laterality of responses can lead to laterality effects, the RCE is still present when response laterality is eliminated by having participants respond verbally naming the direction of the gaze.

Design

We used a 2x2x2x2 mixed design, with Previous Congruency (N-1 Congruent and N-1 Incongruent) Congruency (Congruent and Incongruent) and Stimulus Type (gaze and arrows) as within-participants variables and Group (responding based on “Direction” or “Color”) as a between-participants factor. Reaction times (RT; in ms) and error rates were used as dependent variables.

Results

To conduct the RT analysis, we excluded incorrect responses (5%), response anticipations (0.2%), and lapses (2%). Additionally, three participants were excluded based on accuracy exclusion criteria. The final sample size consisted of N = 49 participants, divided into Direction ($n = 24$) and Color ($n = 25$) groups.

Reaction Time

Following the preregistered analysis plan, we first performed an ANOVA adding Laterality as a factor to test the differences between ipsilateral and contralateral responses in the Color group. Results of RTs showed a main effect of Laterality, $F(1,24) = 12.55$, $p = .002$, $\eta_p^2 = .34$, contralateral responses being slower than ipsilateral ones (712 vs 747 ms) but no interactive effects with any variable. Given the absence of interaction and taking into account the findings of Narganes-Pineda et al (2022*)*, both types of responses were considered in the analysis.

The ANOVA showed a main effect of Stimulus, $F(1,47) = 136.70$, $p < .001$, $\eta_p^2 = .74$, $BF_{incl} = 4.94 \times 10^{32}$, Congruency, $F(1,47) = 54.88$, $p < .001$, $\eta_p^2 = .54$, $BF_{incl} = 1.90 \times 10^7$, and Group, $F(1,47) = 45.46$, $p < .001$, $\eta_p^2 = .49$, $BF_{incl} = 3.11 \times 10^4$, participants being faster responding to arrows than gaze, to congruent than incongruent trials and performing the direction task than the color task (see Table 2). Stimulus and

Congruency interacted significantly, $F(1,47) = 37.01$, $p < .001$, $\eta_p^2 = .44$, $BF_{incl} = 1031$. Partial ANOVA showed a significant standard congruency effect for arrows, $F(1,48) = 108.81$, $p < .001$, $\eta_p^2 = .69$, $BF_{incl} = 5.15 \times 10^{10}$, and a marginal standard effect for gaze, $F(1,48) = 3.60$, $p = .064$, $\eta_p^2 = .07$, $BF_{incl} = .98$. Contrary to our hypothesis, Group did not modulate Congruency, $F(1,47) = 37.01$, $p = .07$, $\eta_p^2 = .07$, $BF_{incl} = 0.58$, nor the Stimulus x Congruency interaction, $F(1,47) = 0.29$, $p = .59$, $\eta_p^2 = .006$, $BF_{incl} = 0.30$.

We also found a significant Previous Congruency x Congruency interaction, $F(1,47) = 559.90$, $p < .001$, $\eta_p^2 = .56$, $BF_{incl} = 1.7 \times 10^4$, that was modulated by Group, $F(1,47) = 24.20$, $p < .001$, $\eta_p^2 = .34$, $BF_{incl} = 68.52$. The predicted pattern of conflict adaptation was found in the Direction Group where, following incongruent conditions, the congruency effect was reduced (4 ms, $t = 0.62$, $p_{holm} = 1$) for arrows and reverted (-34 ms, $t = 4.28$, $p < .001$) for gaze. However, in the Color group, the congruency effect was present after either congruent (42 ms, $t = 7.17$, $p_{holm} < .001$) and incongruent trials (24 ms, $t = 3.97$, $p_{holm} < .001$). Neither the Previous Congruency x Congruency x Stimulus, $F < 1$, $p = .39$, $BF_{incl} = 0.23$ nor the four-way interaction, $F < 1$, $p = .94$, $BF_{incl} = 0.29$ were significant. In summary, and importantly, although the Group modulated congruency sequence effects, with a much-reduced congruency sequence effect when participants responded to the indicated color rather than the direction of targets, it did not modulate the Stimulus x Congruency interaction (Figure 7).

Error Rate

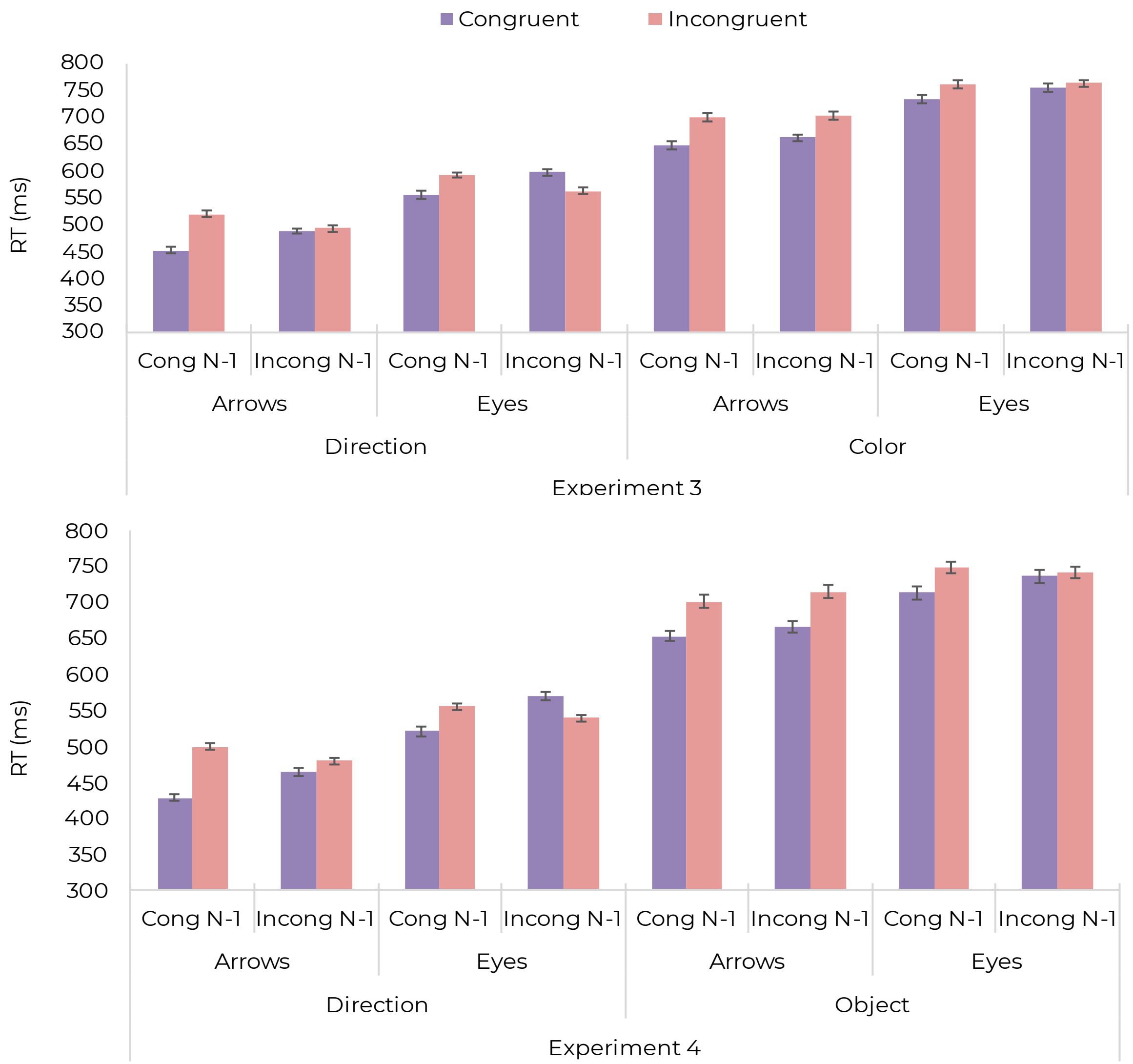
For error rate, the ANOVA showed a main effect of Congruency, $F(1,47) = 30.96$, $p < .001$, $\eta_p^2 = .40$, $BF_{incl} = 4.12 \times 10^6$, and Group, $F(1,47) = 28.09$, $p < .001$, $\eta_p^2 = .37$, $BF_{incl} = 5118$. Participants committed more errors responding to incongruent than congruent conditions and during the color than the direction task. We also found an interactive effect of Previous Congruency and Congruency, $F(1,47) = 11.78$, $p = .001$, $\eta_p^2 = .2$, $BF_{incl} = 21.16$, that was also modulated by Group, $F(1,47) = 6.48$, $p = .014$, $\eta_p^2 = .12$, $BF_{incl} = 3.40$, following a similar pattern to RTs data. In the Direction group, the standard congruency effect was present following congruent trials (0.041, $t = 4.87$, $p_{holm} < .001$) and disappeared after incongruent conditions (0.005, $t = 0.62$, $p_{holm} = 1$).

In the Color group, the standard effect was present after either congruent (0.04, t = .008, $p_{holm} < .001$) or incongruent trials (0.028, $t = 3.42$, $p_{holm} = .012$).

However, again, the results showed that both groups performed at a remarkably high level (Direction, $M = .98$, $SD = 0.15$; Color, $M = .93$, $SD = 0.26$) which requires a cautious interpretation of the error data.

Figure 7

Mean Reaction Time (RT) for Each Group, Object Condition, Stimulus Type, Previous Trial (N-1) Congruency, and Congruency of Experiments 3 and 4



Note. Errors bars represent the standard error corrected with Cousineau's method (2005) to eliminate between-participant variability.

Discussion

In this experiment, we aimed to not only present objects but also force participants to respond by reporting the indicated or observed color. Contrary to our hypothesis, having to respond to colors did not impact the congruency effect observed with gaze. In contrast to the previous study (Aranda-Martín et al., 2023), these effects cannot be attributed to participants ignoring the task set and consequently performing the same task in both groups, as that was not possible in the current experiment. Indeed, we did observe an effect on overall performance, as evidenced by both reaction times and error rates. Participants showed slower response times and lower accuracy when required to report the indicated or looked-at color, compared to when they had to report the direction of arrows and gaze.

Once again, arrows displayed a standard pattern of congruency, whereas gaze showed a reversed congruency sequence effect, which again was only observed after incongruent trials as in Hemmerich et al. (2022) and the previous experiments reported here. This, together with the fact that no sequence congruency effects were observed for the color group, led to the observation that the gaze's RCE only appeared in the Direction group, partially supporting the hypothesis that responding to color would neutralize the "joint distraction" effect and eliminate the reversed effect. However, the absence of conflict adaptation in the Color group was also observed for arrows, suggesting that task characteristics could affect the sequential effects of conflict. The fact that participants had to make a second selection (i.e., left or right response key according to the indicated or looked-at object) after having selected the direction of the target, seems to have overridden the effect of the congruency of the previous trial on the current one. This is an interesting finding that deserves future research.

Nevertheless, for the aim of the research project reported here, it is important to highlight that Group did not modulate the stimulus by congruency interaction. Therefore, having to respond to the looked-at object rather than to the gaze direction did not eliminate the differences in the congruency effect observed between arrows and gaze. Note in Figure 7 that although the color group did not show the RCE for gaze even after incongruent trials due to the reduced or absent congruency sequence effects, the spatial congruency effect observed for gaze was still much reduced compared to that observed for arrows. Thus, the presence of colors and the need to respond to them instead of to the arrow/gaze direction did not affect the Stimulus x Congruency interaction.

Another aspect to consider is that our manipulation may not have been powerful enough to produce interactive effects as colors might not be sufficiently engaging. To address this issue, a simple modification of the task could be to replace colors with pictures of real objects. As discussed in Aranda-Martín et al. (2023), in a real-life scenario, when interpreting gaze direction and intentionality, we typically attend to the focus of interest of our social partner, which could be an object, an action, or another person, but rarely a color per se. Therefore, presenting objects could more properly replicate a real-life situation and may yield stronger effects (Edwards et al., 2020).

Experiment 4: Responding to Objects

In the current preregistered study (osf.io/xzbw2), the bicolor frame was replaced by an image of two real-world objects, the red apple and the green pear of Experiments 1 and 2, changing the preceding Color group for an Object group.

Based on our previous results and following the preregistered hypothesis, we predicted an interactive effect between Group and Congruency specifically for gaze. In other words, we anticipated the Stimulus x Congruency interaction to be modulated by whether participants responded to stimulus direction, in which case we expected to observe the usual dissociation between arrows and gaze, or to the indicated/looked-at object. In this latter case, we expected a similar standard congruency effect for gaze and arrows. More specifically, we anticipated a standard congruency effect when participants responded to the gazed object as objects would be likely able to enhance attentional selection (Edwards et al., 2020) compared to less socially relevant stimuli like a simple color frame.

Method

Participants

We recruited 60 participants (50 female) that were randomly assigned to the two task groups: Direction (n = 30) and Object (n = 30). Due to the previous inconclusive Bayesian results for the gaze effect and following the preregistered plan, we slightly increased the sample size to increase the chances of detecting a small effect size.

Procedure

The procedure, materials, and experimental design for Experiment 4 were similar to those used in Experiment 3 except for presenting the fruit pictures of Experiments 1 and 2 instead of color (Figure 6). Besides the factors noted in Experiment 1, these images had the benefit of matching the frame color in Experiment 3. Response keys were identical to those in Experiment 3 but were distinguished by apple/pear stickers instead of red/green patches.

Results

The same filtering criteria were applied for RT analysis, which included the elimination of incorrect responses (3%), response anticipations (0.4%), and lapses (2%). Three participants were eliminated based on the accuracy exclusion criteria. The final sample size was N = 57, divided into Direction (n = 28) and Object (n = 29).

Reaction Time

The ANOVA again revealed significant effects of Stimulus, $F(1,55) = 75.73$, $p < .001$, $\eta_p^2 = .58$, $BF_{incl} = 5.78 \times 10^{42}$, Congruency, $F(1,55) = 60.35$, $p < .001$, $\eta_p^2 = .52$, $BF_{incl} = 1.25 \times 10^9$, and Group, $F(1,55) = 105.81$, $p < .001$, $\eta_p^2 = .64$, $BF_{incl} = 1.7 \times 10^{11}$, participants being faster responding to arrows than to gaze, to congruent than to incongruent trials and performing the Direction than the Object task. We also found a Stimuli x Congruency interaction, $F(1,55) = 36.46$, $p < .001$, $\eta_p^2 = .40$, $BF_{incl} = 1974$, which, contrary to our hypothesis, was not modulated by Group $F(1,55) = 1.36$, $p = .25$, $\eta_p^2 = .024$, $BF_{incl} = 0.39$.

Similar to Experiment 3, we found a significant Previous Congruency x Congruency interaction, $F(1,55) = 43.15$, $p < .001$, $\eta_p^2 = .44$, $BF_{incl} = 7630$, that was again modulated by Group, $F(1,55) = 15.97$, $p < .001$, $\eta_p^2 = .23$, $BF_{incl} = 13.28$. In the Direction group, the congruency effect disappeared following incongruent conditions (7 ms, $t = 1.13$, $p_{holm} = .53$), while, in the Color group, it was present following either congruent (42 ms, $t = 6.41$, $p_{holm} < .001$) and incongruent trials (27 ms, $t = 4.15$, $p_{holm} < .001$).

To verify whether the objects and colors had distinct effects as anticipated, this being the only difference between Experiment 3 and Experiment 4, we conducted an exploratory analysis by merging data from both experiments. By pooling the data, we were able to increase the sample size to 106 participants (Direction task, $n = 52$, and Object-Color task, $n = 54$), improving the reliability of our conclusions. For tasks responding to items (colors in Experiment 3 or objects in Experiment 4), the Experiment showed no main, $F(1,52) = 0.06$, $p = .81$, $\eta_p^2 = .001$, $BF_{incl} = 0.47$, nor interactive effects (Stimulus x Congruency x Experiment, $F(1,52) < 1$, $p = .92$, $BF_{incl} = 0.23$, Previous Congruency x Congruency x Experiment, $F(1,52) < 1$, $p = .98$, $BF_{incl} = 0.39$), so both color and objects seem to have an analogous impact on the rest of the factors. Similarly, in direction tasks, Experiment did not show main, $F(1,50) = 1.43$, $p = .24$, $\eta_p^2 = .03$, $BF_{incl} = 0.84$, or interactive effects (Stimulus x Congruency x Experiment, $F(1,50) < 1$, $p = .5$, $BF_{incl} = 0.23$, Previous Congruency x Congruency x Experiment, $F(1,50) < 1$, $p = .48$, $BF_{incl} = 0.2$).

Critically, combining the results of both tasks in the two experiments, the three-way interaction of Stimulus x Congruency x Task was still not significant, $F(1,104) = 1.56$, $p = .21$, $\eta_p^2 = .02$, yielding Bayesian evidence supporting the absence of interaction, $BF_{incl} = 0.24$.

Error Rate

For error rate, ANOVA showed a main effect of Congruency, $F(1,55) = 20.12$, $p < .001$, $\eta_p^2 = .27$, $BF_{incl} = 22901$, and Group, $F(1,55) = 6.60$, $p = .013$, $\eta_p^2 = .11$, $BF_{incl} = 3.35$.

Participants committed more errors responding to incongruent than congruent conditions and during the Object than the Direction task. The interaction of Stimulus x Congruency, $F(1,55) = 5.51$, $p = .023$, $\eta_p^2 = .09$, $BF_{incl} = 1.26$, Previous Congruency x Congruency, $F(1,55) = 9.78$, $p = .003$, $\eta_p^2 = .15$, $BF_{incl} = 8.08$, and Previous Congruency x Congruency x Group, $F(1,55) = 5.89$, $p = .019$, $\eta_p^2 = .1$, $BF_{incl} = 2.15$, resulted statistically significant. The error rate data followed a similar pattern to RT. On the one hand, the standard congruency effect shown by arrows (0.02, $t = 4.99$, $p_{holm} < .001$) was absent when responding to gaze (0.009, $t = 2.12$, $p_{holm} = 0.09$). Moreover, the pattern of conflict adaptation was present in the Direction group—a standard effect following congruent trials (0.036, $t = 4.56$, $p_{holm} = .46$) that disappeared after incongruent conditions (0.036, $t = 4.56$, $p_{holm} = .46$)—but not in the Object group as the effect was absent either after congruent (0.016, $t = 2.6$, $p_{holm} = .16$) or incongruent trials (0.013, $t = 1.68$, $p_{holm} = 1$).

Once again, we found a high level of accuracy in both Direction ($M = .97$, $SD = .03$) and Object groups ($M = .96$, $SD = .04$) having the risk of a ceiling effect.

Discussion

As observed in Figure 7, the results again suggest that objects did not influence the congruency effect. Furthermore, the pooled analyses reveal no discernible distinction between objects and colors and provided evidence that the critical stimulus x congruency interaction was not modulated by whether participants had to report the direction of targets, or the color/object indicated or looked at by them.

Therefore, the overall pattern of results consistently observed in the four reported experiments, together with that reported by Aranda-Martín et al. (2023), seems to contradict the predictions derived from the joint distraction hypothesis.

General Discussion

Attentional mechanisms elicited by arrows and gaze stimuli might involve a similar set of processes (i.e., the ability to shift attention in a direction) that reveal analogous behavioral patterns (i.e., similar cueing effects; Chacón-Candia et al., 2023). However, gaze may also trigger attentional effects that are specific and dissociable from those shared with arrows, capturing the mentalizing and socio-communicative ability of gaze. In this study, we aimed to delve into the underlying mechanism of a gaze-specific effect: the Reversed Congruency Effect (RCE). As represented in Figure 1, while arrows and gaze share the initial set of attentional processing that creates a direction-location interference, an added social gaze component may explain the reversion of the congruency observed for gaze, compared to arrows. This phenomenon has been attributed to a *joint distraction* process, define as an attentional drive to “jointly” look for the potential gazed object. Incidentally looking for something that is not there, as during congruent trials where the gaze is looking outward, would increase the time to identify the direction, creating a “joint distraction” situation (Aranda-Martín et al., 2022; Aranda-Martín, 2023, Hemmerich et al., 2022). Throughout this experimental series, we tested this hypothesis by adding objects to the task. The attentional act initiated by gaze direction would be completed on the gaze-at objects, preventing the search for the absent object (joint distraction) and, hence, the RCE.

Contrary to our initial hypothesis, the presence of objects did not seem to influence the congruency effect, whether presented on a trial-by-trial basis (Experiment 1) or in separated blocks (Experiment 2). Even when participants were required to respond to the objects (Experiments 3 and 4), forcing them to perceive and process them, the dissociation in the congruency effect observed for arrows vs. gaze was still present. Overall, the sequential effects of conflict revealed a standard effect of arrows and a reversed congruency effect for gaze. In line with previous research (Hemmerich et al., 2022), the prior experience of conflict seems to reduce the spatial interference shared by arrows and gaze (components “a” and “b” in Figure 1) thus heightening the opposing effect of gaze, therefore finding a standard effect after congruent trials (although reduced compared to arrows) that is reversed following incongruent ones. Critically, the reversed congruency effect observed for gaze persisted even with the presence of objects.

The evidence presented in this and previous studies (Chacón-Candia, Román-Caballero, et al., 2023; Hemmerich et al., 2022; Marotta et al., 2019) supports the idea that gaze produces additional attentional effects, such as the RCE, that are specific and dissociable from those shared with nonsocial stimuli. However, our findings challenge the hypothesis that joint distraction is the social mechanism responsible for the RCE (component “C” in Figure 1). Despite the presumed “distraction” would be overruled by the presence of objects, the RCE persisted, suggesting that other factors may be at play. Perhaps the reversion (i.e., slower responses on congruent trials) is indeed related to a search for an object that would be attentionally selected, but the interfering effect of this "looking vector" may only be captured at later stages of processing, making it necessary to shift the focus from the perception or identification of objects and instead consider effects beyond attentional selection. For instance, despite being irrelevant, participants might be distracted by the selected object allocating their attentional resources toward it.

These post-perceptual effects fit the aforementioned electrophysiological data that found a dissociation between gaze and arrows on late ERP components (Marotta et al., 2019), suggesting that gaze-specific components emerge in later processing stages. An illustrative example of the effects of gaze beyond the initial perceptual episode was provided by Gregory and Jackson (2017). The authors used a cueing task with arrows and eyes as central cues and colored squares as targets, combined with a visual working memory task. Both cues equally facilitated target detection, but only gaze influenced working memory as the gazed-at colors were better reported from working memory than those indicated by arrows. The benefit of following other people’s gaze on object processing has been observed even in infants. As shown by Okumura et al., (2017) the ability to follow gaze direction at 9 months enhanced object processing and increased vocabulary at 18 months. Importantly, the vocabulary growth was not linked to the length of time the object was fixated upon, but rather to whether it had previously been looked at by another person.

Another point to note is that in the current set of experiments, we did not find an overall significant RCE for gaze in the direct effect of congruency, but only when considering the congruency of the previous trial. Indeed, the RCE of gaze was significantly observed only after incongruency trials. The RCE is a robust and widely replicated effect, but it seems to comprise two coexisting opposite effects: the spatial and orienting mechanisms responsible for the direction-location interference common to all directional stimuli, and the social component exclusive to gaze. The latter may be easier to detect by subtracting the commonalities, such as through conflict adaptation. In this regard, since we used a new variation of the original task, we cannot rule out the possibility that certain details in the design may have affected either the spatial interference effect shared by arrows and gaze, or the component specific to gaze, in a way that hinders the overall measure of the RCE. For instance, the pre-exposure to objects along with fixation, before the appearance of targets, could have had an unanticipated effect.

According to the referential coding account proposed by Hommel (1993), stimulus location is coded relative to an object of reference. The prior presence of items (color or objects) may modify how space is encoded and subsequently affect interference effects. While it did not eliminate the RCE, as evidenced by the sequential effect, it could have weakened it by exposing participants to a spatial configuration where objects were already present (Román-Caballero et al., 2021a, 2021b; Virzi & Egeth, 1985). Actually, pre-exposing participants to some of the target elements, such as presenting the same face with closed eyes prior to the target face, reduces the RCE (Román-Caballero et al., 2021a). In a similar vein, the objects could be pre-selected before the target appearance. Since participants have already seen the objects, the potential influence of gaze or arrow direction may be reduced, even in groups where participants are specifically instructed to respond to objects.

Another possibility is that the presence of an object on each side of the screen may have not eliminated but somehow hindered the joint distraction effect. Some studies suggest that gaze could orient attention specifically to the particular location being gazed at (Chacón-Candia et al., 2020; Marotta et al., 2012). Furthermore, this attentional bias depends on perceiving the looked-at area as an object (Chacón-Candia et al., 2023). Although, as predicted, objects would prevent joint distraction in congruent trials, they could also affect incongruent conditions. An automatic selection of objects based on gaze direction may take longer on incongruent conditions, where the object is located on the opposite side of the screen, than on congruent ones, resulting in an RCE. Although object selection could also occur at the fixation point in incongruent trials, real objects may have a stronger influence (Edwards et al., 2020).

In summary, the debate about the nature of this gazed-specific reversed congruency effect continues, as our hypothesis was disconfirmed. Further research is needed to explore the underlying mechanisms and social significance of this phenomenon, as well as its possible consequences beyond perception. For instance, based on the findings of Gregory et al. (2017), the RCE may affect memory performance and therefore objects gazed at during congruent conditions would be better recalled. For testing this possibility, it would be necessary to use a different experimental approach, like adding a final recognition phase, in which memory for objects would be tested. Overall, the findings of the research reported here contribute to our understanding of the complexities of gaze direction processing and highlight the need for further investigation.

Chapter 4

Individual Differences

3 Study III

Integration of facial expression and gaze direction in individuals with a high level of autistic traits

This study has been published as:

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Abstract

Background. We investigated whether individuals with high levels of autistic traits integrate relevant communicative signals, such as facial expression, when decoding eye gaze direction. Methods. Students with high vs. low scores on the Autism Spectrum Quotient (AQ) performed a task in which they responded to the eye directions of faces, presented on the left or the right side of a screen, portraying different emotional expressions. Results. In both groups, the identification of gaze direction was faster when the eyes were directed toward the center of the scene. However, in the low AQ group, this effect was larger for happy faces than for neutral faces or faces showing other emotional expressions, whereas participants from the high AQ group were not affected by emotional expressions. Conclusions. These results suggest that individuals with more autistic traits may not integrate multiple communicative signals based on their emotional value.

Introduction

Faces are among the most important visual stimuli, conveying complex information of considerable importance in the context of social interactions, including identity, race, sex, attractiveness, and emotions (Bar-Haim et al., 2006; Röder et al., 2013; Yankouskaya et al., 2012). Humans have a marked preference for real face visual features and face-like configurations very early in their ontogeny. Infants, and even fetuses, show a visual preference for basic face-like configurations (Buiatti et al., 2019; de Heering & Rossion, 2015; Striano & Reid, 2006). This preference is very functional to the newborn, facilitating connection with the caregiver and evoking a response (Shultz et al., 2018). Infants use a wide variety of social signals to respond contingently to their social partner, for instance, coupling their facial movements and vocalizations with the facial expression of their caregivers (Bigelow & Power, 2016; Smith, 2005). The preference for face visual features has alsobeen observed in school-aged children (Fischer et al., 2016; Shaffer et al., 2017; Wilson et al., 2010) and in adults (Crouzet et al., 2010; Fletcher-Watson et al., 2008; Shah et al., 2013). For example, masked faces are detected more quickly and accurately than masked objects (Purcell & Stewart, 1988), and facial changes are better detected than changes in non-facial objects (Kikuchi et al., 2009).

Among the changeable aspects of the face, gaze shifts and facial expressions are crucial. They serve as powerful social signals that allow humans to infer internal states and intentions. Gaze direction signals another person's focus of interest and can orient our attention to potentially relevant locations or objects in the surrounding space (Friesen & Kingstone, 1998; Marotta, Casagrande, et al., 2013). When interpreting eye gaze direction, people consider information from different sources, such as the iris/sclera ratio (Ando, 2004), the head posture (Langton, 2000), the presence of an object near the fixation point of another person's (Lobmaier et al., 2006) and, of relevance for the present study, the emotional facial expression. Facial expressions of other people can help to determine the emotional state or motivational intentions, and several pieces of evidence indicate that the processing of gaze direction and emotional expression mutually interact.

On the one hand, some studies have observed that gaze direction can modulate the time to judge facial expressions. For example, faces expressing anger or joy are recognized more quickly when presented with gaze directed at the viewer than when presented with gaze averted. In contrast, sadness and fear are recognized faster with averted gaze (Adams & Kleck, 2003, 2005). Adams and Kleck interpreted these findings in terms of a shared signal hypothesis, in which happiness and anger are considered 'approach-oriented' emotions and sadness and fear 'avoidance-oriented'.

On the other hand, the perception of gaze direction is modulated by emotional expressions. For example, Lobmaier and Perrett (2011) asked participants to judge whether faces presented in different orientations and with different facial expressions were looking towards them. They found that smiling faces are more likely to be interpreted as directed towards the observer than fearful, angry, and neutral faces. These findings are not consistent with the shared signal hypothesis, and they have been explained by the "self-referential positivity bias" hypothesis (Pahl & Eiser, 2006), according to which people are more likely to believe that they are the source of someone else's happiness, so as to improve self-esteem.

Reduced interest in the human face and malfunctioning of the above described face-related attentional processes represent some of the most pronounced social deficits associated with autism spectrum disorder (ASD) (American Psychiatric Association, 2013; Bird et al., 2006; Pelphrey et al., 2002). A large amount of empirical evidence has highlighted the presence of an atypical imbalance in attention to social versus nonsocial stimuli in ASD (Volkmar, 2011). Children and adults with ASD exhibit poorer recognition memory for faces and reduced visual attention to facial stimuli than typically developing (TD) individuals (Guillon et al., 2014; Kirchner et al., 2011). Neurophysiological evidence also corroborated the presence of abnormal facial processing in ASD. For example, recent studies combining EEG and eye-tracking measures have observed a reduction in social bias and an abnormal orientation to faces in individuals with ASD (Vettori, Dzhelyova, et al., 2020; Vettori, Van der Donck, et al., 2020). Eye-tracking research has also shown that a reduced fixation to the eye area in ASD (Chita-Tegmark, 2016) can result in significant differences in brain activation. For instance, people with ASD showed greater activation in the social neural network to averted than to direct gaze, this pattern being the opposite of that observed in TD (Georgescu et al., 2013). Nevertheless, those differences do not seem to affect the interpretation of gaze direction and object detection but rather the ability to infer gaze intentionality (Face Processing in Autism Spectrum Disorders: From Brain Regions to Brain Networks, 2015).

Indeed, some studies have shown that people with ASD are equally adept at correctly identifying the direction of a gaze as TD individuals (Baron-Cohen et al., 1995; Leekam et al., 1997; Macinska, 2019; Wallace et al., 2006). However, they seem to present difficulties in integrating gaze direction with communicative and social contexts (Baron-Cohen, Baldwin, et al., 1997; Pelphrey et al., 2005). In particular, of relevance for the present study, Akechi et al. (2009) observed that autistic children had a deficit in integrating the information of facial expressions with gaze direction.

Additionally, several research studies have suggested that ASD represents the upper extreme of a pattern of social–emotional and communicative traits continuously distributed in the general population (Constantino & Todd, 2003; Piven et al., 1997; Spiker et al., 2002). Initial support comes from studies demonstrating that the degree of autistic traits measured by the Autism Spectrum Quotient (AQ) in a typical population (Baron-Cohen et al., 2001) is related to performance on behavioral tasks that show impairments in ASD, such as the ability to draw mentalistic inferences from the eyes (Baron-cohen, 2001) the identification of emotional facial expressions (Poljac et al., 2012), and the attentional cueing from eye gaze (Bayliss et al., 2005; Bayliss & Tipper, 2005).

The main aim of the present study was to investigate whether individuals with high levels of autistic traits integrate facial expressions when decoding eye gaze direction. As mentioned above, the combination of expression and gaze direction provides essential information for understanding another individual's intentions, and difficulties in their encoding and integration have been observed in ASD. However, it is not clear whether this impairment is directly related to autism traits per se or rather depends on different social communication patterns formed by years of altered social experience. Testing individuals who function normally in their everyday lives would allow testing the specific contribution of autistic traits, minimizing the influence of experience, such as the amount of social involvement.

To achieve this aim, we used the gaze discrimination task developed by Cañadas & Lupiáñez (2012), to explore the importance of eye gaze direction in spatial interference paradigms. These authors demonstrated that gaze direction discrimination of a lateralized face (i.e., presented to the left or right of fixation point) is faster and more accurate when the gaze is oriented inwards, towards the center of the scene (e.g., right averted gaze presented on the left) than when it is directed outwards (e.g., right averted gaze presented on the right). This effect was opposite that of the classical results generally observed with nonsocial stimuli, such as arrows (e.g., faster reaction time for arrows pointing outwards) (Marotta et al., 2018), and it was interpreted in terms of eye contact (e.g., a speeding up of responses when the target face seems to look directly at the participants). A further investigation revealed that the emotional expression of the face modulated the inward effect (Jones, 2015) according to the "shared signal hypothesis" (Vettori, Dzhelyova, et al., 2020; Vettori, Van der Donck, et al., 2020): the effect was larger when it was coupled with approach-oriented emotions such as happiness and anger, while it was smaller for the avoidance-oriented emotions such as fear.

The predictions of the present study were straightforward. If the degree of autistic traits in the typical population is related to the difficulties in integrating gaze direction with communicative and social contexts generally observed in ASD, then these difficulties should be observed only in participants with high levels of autistic traits but not in participants with low autistic traits. In other words, the identification of gaze direction should not be affected by the emotional expression of facial stimuli in participants with high levels of autistic traits, while the inward effect from gaze direction should be modulated in participants with low levels of autistic traits.

Moreover, there are two possible scenarios regarding the modulation of facial expressions on the identification of gaze direction in participants with low autistic traits. If the emotional expression modulates the identification of gaze direction, according to the shared signal hypothesis (Vettori, Dzhelyova, et al., 2020; Vettori, Van der Donck, et al., 2020), then a larger inward effect should be observed with both happy and angry faces (approach-oriented emotions) as compared with sad and fearful faces (avoidance-oriented emotions). In contrast, if the identification of gaze direction is modulated by emotional expression according to the "self-referential-positivity bias hypothesis" (Lobmaier & Perrett, 2011; Pahl & Eiser, 2006), then the inward effect should be larger for happy faces than for faces showing other emotional expressions or a neutral expression.

Method

Participants

Initially, 459 students completed the AQ (mean (M) score = 16.29; standard deviation (SD) = 5.88). Next, 36 students from the upper and lower quartiles of the AQ distribution (using cutoff scores equal to or lower than 11 and scores equal to or higher than 22) were invited to complete further testing. Based on previous research (Hudson et al., 2012; Zhao et al., 2015), we decided to use permissive cutoff scores for reasons related to sample size since only 1.74% of the initial group would have met the clinical AQ cutoff scores of 32 (Baron-Cohen et al., 2001). All participants from the initial group were undergraduate psychology students. Women were overrepresented in the initial group (80%) and the sample selected for this study (86.11%). The characteristics of the high and low AQ groups are outlined in Table 1. The groups did not differ significantly in age distribution, $F(1,34) < 1$. Numerically, there was a higher proportion of females in the high AQ group than in the low AQ group, but this difference was not statistically significant, $\chi2(1) = 2.09$, $p = 0.148$. There were no significant socio-demographic (e.g., education, ethnic origin, native language) differences between these two groups.

Table 1

Male–Female Ratio and Means (SDs) for AQ Score and Age.

	Low AQ			**High AQ**		
	Mean	SD	N(male/female)	Mean	SD	N(male/female)
Age (years)	18.89	1.6	1:17	20.44	3.01	4:14
AQ score	8.28	1.84		24.61	3.18	

The Autism Spectrum Quotient (AQ)

The AQ is a 50-item self-report questionnaire designed for measuring autistic traits in the general population (Baron-Cohen et al., 2001). In particular, it assesses five different domains relevant for autistic traits: social skills, attention to detail, attention switching, communication, and imagination. This instrument (retrieved from https://www.autismresearchcentre.com, accessed on 8th of April 2018, see Appendix 1) has been used specifically for quantifying where participants are situated on the continuum from autism to normality. The AQ score has been shown to have good test–retest reliability, good internal consistency, and acceptably high sensitivity and specificity (Baron-Cohen et al., 2001).

Apparatus and stimuli

The E-Prime 2.0 software (Psychology Software Tools Inc, Pittsburgh, PA, USA) was used to control stimuli presentation, timing, and data collection. Stimuli were presented on a 17” screen running at a 1024 x 768-pixel resolution. They consisted of 40 full-color photographs of four males and four females (dimensions = 180 x 200 pixels or 6.67° x 5.72°) displaying either a neutral, angry, sad, fearful, or happy emotional expression. Faces were selected from the Karolinska Directed Emotional Faces (Lundqvist et al., 1998)and were manipulated with Adobe Photoshop CS6 to change gaze directions to the left and right sides.

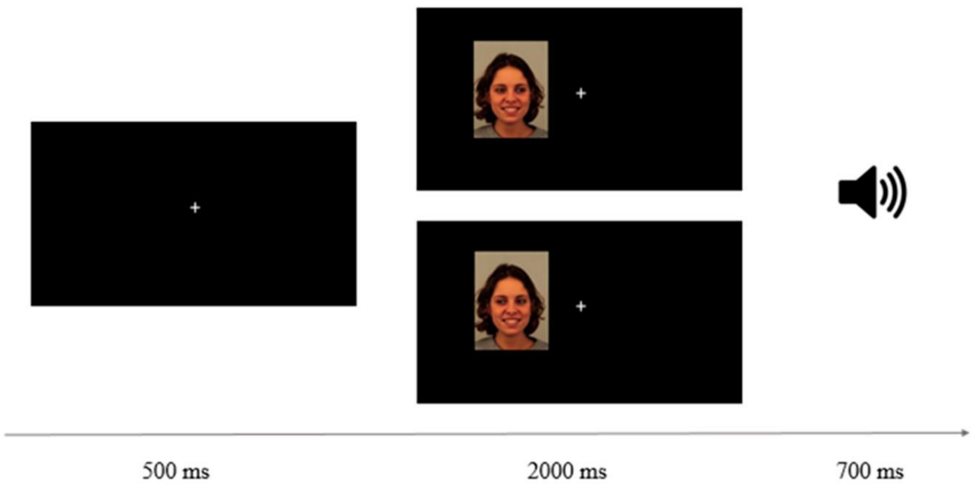
Procedure

Gaze Discrimination Task.

Participants were required to discriminate, as fast and accurately as possible, the direction (left or right) of the eye gaze of the faces presented to the right or the left of a fixation point. They were tested while seated at approximately 60 cm away from the monitor in a faintly lit room. Each trial started with the onset of a white fixation cross (0.5° x 0.5°) centered on a black computer screen for 500 ms. Then, a face displaying different emotional expressions, was presented either to the right or left of the fixation cross and gazing either to the right or left (see Figure 1). The distance from the inner edge of the face to the central fixation was approximately 3.02°. Importantly, this design produced inward trials where eyes were directed towards the central fixation location (i.e., a right-averted gaze of faces presented on the left, and a left-averted gaze of faces presented on the right) or outward trials (i.e., a left-averted gaze presented on the left and a right averted gaze presented on the right). Participants had to discriminate the gaze direction of the face by pressing the "Z" or "M" key of the computer keyboard when the correct answer was left or right, respectively. Feedback on no-response or incorrect response trials was provided via a 220 Hz tone for 700 ms. All possible combinations of stimuli, 8 (face identity) x 5 (emotional expression) x 2 (presentation side) x 2 (gaze direction), formed a total of 160 trials. Two blocks of trials with all combinations were presented for a total of 320 trials. Participants completed a practice block of 16 randomly selected trials to familiarize themselves with the task, followed by eight experimental subblocks of 40 randomly selected trials each, with a rest period between blocks.

Figure 1

Schematic View of a Trial Sequence From Left to Right



Note. The examples illustrate, from top to bottom, an inward and an outward trial of a woman with an emotional expression of happiness. The speaker icon represents the auditory feedback given on incorrect answers.

Emotional Expression Categorization Task.

After completing the gaze discrimination task, participants were prompted to pay attention to the screen for one last activity, in which they had to identify the emotional expressions of the same faces presented in the previous task. Faces with a direct gaze displaying either angry, happy, sad, neutral, or fearful emotional expressions appeared at the center of the screen for an unlimited time. Participants were required to identify the expression of faces by typing the answer on a computer keyboard.

Design

A 2 (Group: high AQ vs. low AQ) x 5 (Emotional Expression: happy, angry, fearful, neutral, or sad) x 2 (Gaze: inward trials vs. outward trials) mixed design was used to analyze the data. The extent of AQ traits was treated as a between-participants variable, and emotional expression and gaze direction represented within-participants factors. Two univariate analyses of variance (ANOVA) separately considered mean corrected RTs and percentage of errors as dependent variables. If the relevant high-order interactions were significant, the inward effect will also be calculated (inward trials—outward trials) and used as a dependent variable in the Bonferroni post hoc testing. As in the Cañadas and Lupiáñez study (2012), trials with reaction times (RTs) faster than 200 ms (0.2% of the trials) or slower than 1300 ms (0.8% of the trials) were considered anticipations and lapses, respectively, and were excluded from the RTs analysis, together with incorrect responses (5.5% of the trials). Mean RTs were computed for each experimental condition using the remaining observations (see Table 2).

Table 2

Mean Correct Reaction Times (RT, ms), Standard Deviations (SD), and Percentages of Incorrect Responses Errors (%IR) as a Function of Emotional Expression, Gaze, and Group (High and Low Scores on AQ).

		Low AQ			High AQ		
Emotions	**Gaze**	**RT**	**SD**	**%IR**	**RT**	**SD**	**%IR**
Happy	Outward	643.4	73.03	5.579	662.8	84.62	10.77
	Inward	585.0	65.55	3.000	638.6	95.18	5.33
Angry	Outward	632.1	84.27	8.684	682.3	95.95	9.278
	Inward	619.0	74.56	6.632	647.8	91.05	4.83
Fearful	Outward	610.3	67.23	3.842	645.6	86.67	6.44
	Inward	582.9	65.70	4.105	628.1	88.33	2.72
Neutral	Outward	614.2	63.59	3.842	661.5	86.96	5.83
	Inward	602.4	78.22	3.895	629.4	94.92	4.167
Sad	Outward	624.6	72.24	5.053	670.0	95.25	6.77
	Inward	596.2	78.37	4.947	628.5	80.85	4.61

Results

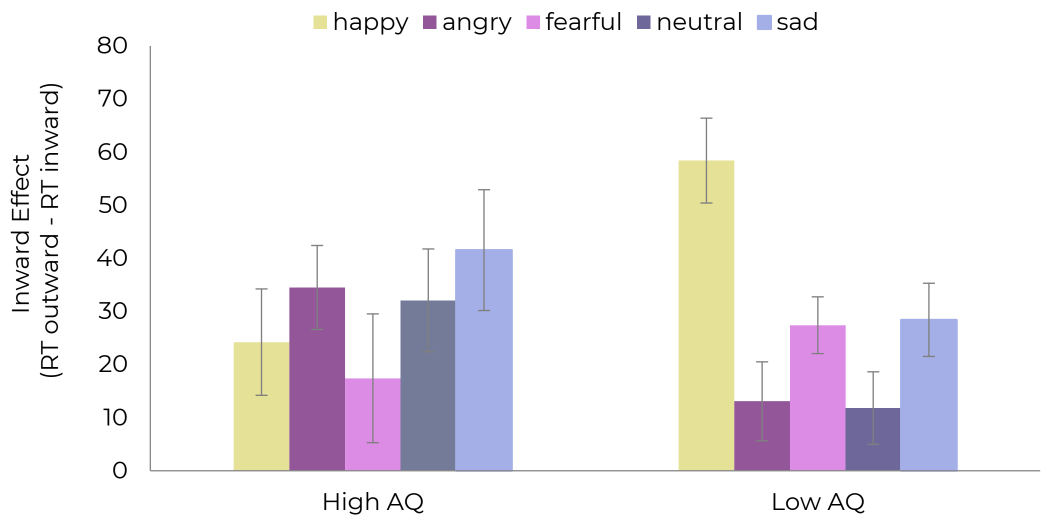
Gaze discrimination task

Reaction Times

The ANOVA revealed a significant main effect of Emotional Expression, $F(4,136) = 13.68$, $p < 0.001$, $\eta^2_p = 0.29$, with the lowest reaction times for fearful faces (617 ms) and the highest for angry faces (645 ms). The main effect of the Group was not significant, $F(1,34) = 2.16$, $p = 0.15$. A main effect of Gaze was also found, $F(1,34) = 48.85$, $p < 0.001$, $\eta^2_p = 0.59$, with faster RTs for inward (616 ms) than for outward trials (645 ms). Furthermore, significant interactions were observed between Emotional Expression and Gaze, $F(4,136) = 3.14$, $p = 0.016$, $\eta^2_p = 0.08$, and between Group, Emotional Expression, and Gaze, $F(4,136) = 5.84$, $p < 0.001$, $\eta^2_p = 0.15$ (see Figure 2). Emotional Expression x Gaze ANOVAs were conducted separately for each Group, showing that the interaction was only significant in the low AQ group, $F(4,68) = 7.12$, $p < 0.001$, $\eta^2_p = 0.29$. Post hoc test using the Bonferroni correction revealed an inward gaze effect (RT outward trials—RT inward trials) significantly larger for happy faces compared with neutral (mean difference = 46.61, $p < 0.001$), anger (mean difference = 45.33, $p < 0.001$), fear (mean difference = 31.00, $p = 0.03$), or sadness (mean difference = 29.99, $p = 0.04$) faces, as shown in Figure 2. No other significant difference between emotions was found. In the high AQ group, the Emotional Expression by Gaze interaction was not significant, $F(4,68) = 1.81$, $p = 0.137$, $\eta^2_p = 0.09$. Post hoc analysis revealed no difference between any emotion (all $p > 0.05$).

Figure 2

Mean Reaction Times for the Inward Effect as a Function of Emotional Expressions and Group.



Note: The inward effect is the difference in RTs between outward and inward trials. Error bars represent the standard error of the mean for each condition.

Errors

The ANOVA revealed a significant main effect of Emotional Expression, $F(4,136) = 5.56$, $p < 0.001$, $\eta^2_p = 0.14$, with the lowest percentage of errors being for fearful faces (4.1%) and the highest for angry faces (6.9%). A main effect of Gaze was also found, $F(1,34) = 7.40$, $p = 0.01$, $\eta^2_p = 0.18$, with a lower percentage of errors for inward trials (4.2%)than for outward trials (6.3%). The main effect of Group was not significant, $F(1,34) = 1.53$, $p = 0.224$, $\eta^2_p = 0.04$. The Emotional Expression x Group interaction was also significant, $F(4,136) = 2.80$, $p = 0.028$, $\eta^2_p = 0.08$. Post hoc test using the Bonferroni correction showed that the Low AQ group committed more errors responding to angry faces than happy (mean difference = 3.28, $p = 0.05$) and neutral ones (mean difference = 3.33, $p = 0.04$). However, the high AQ group committed more errors responding to happy faces than to fearful ones (mean difference = 3.47, $p = 0.027$). No other differences between groups or emotions were found. No other interaction reached significance.

Emotional expression identification

For the analysis of responses in the emotional expression task, a 2 (Group: high AQ vs. low AQ) 5 (Emotional Expression: happy, angry, fearful, neutral, or sad) mixed design was conducted with the accuracy of responses as the dependent variable. The analysis of accuracy data indicated a main effect of emotional expression, $F(4,136) = 2.80$, $p < 0.001$, $\eta^2_p = 0.48$. The highest accuracy was observed for faces displaying happiness (97.9%) and the lowest for neutral faces (45.1%). Importantly, the results show that Group did not have any effect, $F < 1$, and did not modulate the effects of emotional expression, $F < 1$.

Discussion

The present study examined the modulation of people's autistic traits in the discrimination of the eyes direction of faces expressing different emotions. In particular, we aimed to investigate whether the ability to integrate facial expression when decoding eye gaze direction depended on the extent of autistic-like traits measured with the AQ. Both low and high AQ groups showed that the identification of gaze direction was faster when the eyes were directed towards the center of the scene (inward effect). It is interesting that participants from the high AQ group also showed this effect, as it has been recently shown that it is not observed until late childhood, with 4-year-old children showing instead a similar effect for gaze and arrows in this task (Aranda-Martín et al., 2022b)

However, this effect was mediated by facial expressions only in the group with low autistic traits, so the inward effect was larger for happy faces than for neutral faces or faces showing other emotional expressions. This finding contrasts with the pattern of results observed by Jones (Jones, 2015) in the general population.

Consistent with the shared signal hypothesis, Jones showed larger inward effects when faces displayed approach-oriented emotions and smaller effects with avoidance-oriented emotions. In contrast, our findings revealed a distinction between negative and positive emotions and are more coherent with the self-referential-positivity bias hypothesis, according to which people prefer to interpret positive emotions as being directed towards them and negative facial expressions as directed away, in order to enhance self-esteem (Lobmaier & Perrett, 2011; Pahl & Eiser, 2006). However, it is important to note that the shared signal hypothesis has been generally used to explain how the recognition of emotional expressions is affected by eye gaze direction (Vettori, Dzhelyova, et al., 2020; Vettori, Van der Donck, et al., 2020), while the self-referential-positivity bias hypothesis has been generally used to explain how the identification of gaze direction is affected by emotional expression (Lobmaier & Perrett, 2011; Pahl & Eiser, 2006). In our study, participants were required to identify gaze direction (left or right) of faces with different emotional expressions. In line with the self-referential-positivity bias predictions, we observed that the inward effect was larger for happy faces than for neutral faces or faces showing other emotional expressions in the AQ Low group. There are some discrepancies between Jones' study and ours. For example, Jones (2015) used four facial expressions (happy, angry, fearful, and neutral), while our faces showed happy, angry, fearful, sad, and neutral expressions. Second, our participants were selected according to their autistic traits scores (e.g., students from the upper and lower quartiles of the AQ distribution), while in the Jones' study, participants were recruited from the general population and were not selected based on their autistic traits. Therefore, it can be suggested that the different results of our study compared with Jones's can be traced back to the autistic traits, high or low. However, future studies are needed to fully elucidate the reasons for these different findings.

Of relevance, data from the present study further show that participants with high levels of autistic traits were not affected by the facial expression of the stimuli when decoding gaze direction. Note that the current finding cannot be explained by a general difficulty of individuals with high levels of autistic traits in decoding gaze direction because in the gaze discrimination task, we did not find any group differences in overall accuracy or RTs. At the same time, we found no group differences in the overall accuracy of the facial emotion identification task, which suggests that the absence of interaction between emotional expression and gaze direction in participants with high levels of autistic traits cannot be attributed to a general difficulty in decoding facial emotional expressions. Our findings are in line with studies showing that autistic individuals have difficulties integrating communicative signals present in the eyes with social and communicative contexts (Baron-Cohen, Baldwin, et al., 1997; Pelphrey et al., 2005) and with their emotional value (Akechi et al., 2009). A possible explanation for why participants with high levels of autistic traits do not show a greater inward effect for happy faces may be related to a weaker self-referential-positivity bias of this group as compared with the low AQ group of participants. This is in line with previous research suggesting reduced positive self-evaluations in ASD (Mezulis et al., 2004; Williamson et al., 2008), and it is coherent with previous research showing that judgments of persons with ASD appear to be less strongly modulated by the emotional value of the available information (Kuzmanovic et al., 2019). Another explanation may also be that these results are related to a decreased reward in the social interaction of individuals with high AQ. For this reason, they would appear to be less influenced by happy faces than people with low AQ. This corroborates previous evidence of a reduced reward value of smiling faces in autistic people compared with typical individuals (Sepeta et al., 2012). Finally, the lack of integration between eye gaze direction and emotional expressions may be based on perceptual or cognitive style, such as weak central coherence which is not specific to the social domain. Individuals with ASD exhibit weak central coherence, which is an impaired ability to integrate individuals' features into a coherent percept (Happé & Frith, 2006). If this impairment extends to those with high ASD traits, this could have impeded the integration of gaze direction and facial expression observed in our study.

To summarize, findings from the present study suggest that the integration between facial expression and gaze direction may be absent or reduced in individuals with a high level of autistic traits. Emotional expression is a key factor when interpreting eye gaze direction. For instance, smiling faces are more likely to be interpreted as being directed toward the observer than fearful, angry, and neutral faces (Lobmaier & Perrett, 2011; Pahl & Eiser, 2006). Our results indicate that this is not the case for individuals with high levels of ASD traits. Previous data using different emotional tasks suggested that ASD participants were not affected by gaze direction when recognizing facial expressions (Akechi et al., 2009). We report for the first time that individuals with high ASD traits display a similar absence of integration between these two types of social cues. In particular, in our study, the inward effect elicited by the gaze direction was not affected by the face's emotional expression. This extends the cognitive socio-emotional similarities between ASD and individuals with high autistic traits and contributes to the dimensional view of ASD as the pathological extreme of a phenotype continuously distributed in the general population. Further studies are needed to investigate the ability of individuals with ASD to encode and integrate non-verbal social cues, which could reveal the source of communication and social interaction difficulties in ASD.

Appendix 1

COCIENTE DEL ESPECTRO AUTISTA PARA ADULTOS (AQ)
Más de 16 años

EJEMPLAR DE USO EXCLUSIVO PARA INVESTIGACIÓN

Para mayor información, consulte:

S. Baron-Cohen, S. Wheelwright, R. Skinner, J. Martin and E. Clubley, (2001)
The Autism Spectrum Quotient (AQ): Evidence from Asperger Syndrome/High Functioning Autism, Males and Females, Scientists and Mathematicians
Journal of Autism and Developmental Disorders 31: 5-17

Nombre:...**Sexo:**..

Fecha de nacimiento:.. **Fecha Actual:**.......................................

Cómo rellenar este formulario

A continuación, encontrará una lista de frases. Por favor, léalas atentamente e indique la respuesta más apropiada.

NO DEJE NINGÚNA FRASE SIN RESPONDER

Ejemplos:

Ej.1. Me gusta correr riesgos	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
Ej.2. Me gusta jugar a juegos de mesa	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
Ej.3. Me resulta fácil aprender a tocar instrumentos musicales	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
Ej.4. Me fascinan otras culturas	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo

1. Prefiero hacer las cosas con otras personas en lugar de hacerlas sólo	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
2. Prefiero hacer las cosas siempre de la misma manera	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
3. Cuando trato de imaginarme algo, me resulta fácil crear la imagen en mi mente	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
4. Frecuentemente me concentro tanto en una cosa que no presto atención a otras cosas	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
5. A menudo escucho ciertos sonidos que las otras personas no oyen	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
6. Normalmente presto atención a las matrículas de los coches, u otras informaciones similares	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
7. Las otras personas frecuentemente me dicen que lo que yo digo es maleducado aunque yo en realidad no creo que sea así	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
8. Cuando estoy leyendo un libro me resulta fácil imaginarme como son los personajes de la historia	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
9. Me interesan mucho las fechas	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
10. Cuando estoy en una reunión me resulta fácil seguir varias conversaciones a la vez	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
11. Las situaciones sociales me resultan fáciles	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
12. Suelo prestar atención a detalles que otras personas no ven	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
13. Prefiero ir a una biblioteca en lugar de ir a una fiesta	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
14. Me resulta fácil inventar historias	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
15. Me siento más atraído por las personas que por las cosas	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
16. Suelo tener un fuerte interés por ciertas cosas y me molesta si no puedo realizarlas	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
17. Me gusta charlar	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
18. Cuando yo hablo apenas dejo hablar a los demás	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
19. Me interesan mucho los números	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
20. Cuando leo un cuento me resulta muy difícil interpretar las intenciones de los personajes	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
21. No disfruto especialmente con los libros de ciencia ficción	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo

22. Me resulta difícil hacer nuevos amigos	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
23. Siempre descubro patrones en las cosas	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
24. Prefiero ir al teatro que a un museo	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
25. No me molesta si mi rutina diaria se modifica	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
26. Frecuentemente noto que me cuesta mantener una conversación con otra persona	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
27. Me resulta fácil "leer entre líneas" o captar el doble sentido, cuando alguien me está hablando	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
28. Normalmente me concentro más en el todo que en los detalles	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
29. No soy bueno para recordar números de teléfono	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
30. Normalmente no noto pequeños cambios en una situación o en el aspecto de una persona	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
31. Me doy cuenta cuando una persona con la que estoy hablando se aburre	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
32. Me resulta fácil hacer más de una cosa a la vez	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
33. Cuando hablo por teléfono me cuesta darme cuenta de cuando es mi turno para hablar	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
34. Me gusta hacer las cosas espontáneamente (sin planificar)	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
35. A menudo soy el último en entender una broma	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
36. Me resulta fácil imaginarme lo que una persona puede estar pensando o sintiendo sólo con mirarla a la cara	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
37. Puedo retomar lo que estaba haciendo después de una interrupción	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo

38. Soy bueno charlando	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
39. La gente me dice que suelo hablar siempre de un mismo tema	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
40. Cuando era más pequeño me gustaba jugar con los demás a juegos de imaginación	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
41. Me gusta recabar información sobre clases de cosas (por ejemplo, tipos de coches, de pájaros, de trenes, de plantas, etc.)	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
42. Me resulta difícil imaginarme como sería ser otra persona	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
43. Me gusta planificar cuidadosamente las actividades en las que participo	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
44. Disfruto de las reuniones sociales	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
45. Me resulta difícil identificar las intenciones de las otras personas	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
46. Las situaciones nuevas me ponen ansioso	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
47. Me gusta conocer gente nueva	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
48. Soy bastante diplomático	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
49. No soy muy bueno para recordar fechas de cumpleaños	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo
50. Me resulta fácil jugar a juegos de imaginación con niños	Totalmente de acuerdo	Bastante de acuerdo	Un poco de acuerdo	Nada de acuerdo

Desarrollado por:

The Autism Research Centre

University of Cambridge

Chapter 5

Developmental course

4 Study IV

What gaze adds to arrows: Changes in attentional response to gaze vs. arrows in childhood and adolescence.

This study has been published as:

Aranda-Martín, B., Ballesteros-Duperón, M. Á., & Lupiáñez, J. (2022). What gaze adds to arrows: Changes in attentional response to gaze versus arrows in childhood and adolescence. *British Journal of Psychology*, 113(3), 1–21. https://doi.org/10.1111/bjop.12552

Abstract

From an early age, gaze acts as a cue to infer the interests, behaviors, thoughts, and emotions of social partners. Despite sharing attentional properties with other nonsocial directional stimuli, such as arrows, gaze produces unique effects. A spatial interference task revealed this dissociation. The direction of arrows was identified faster on congruent than on incongruent direction-location trials. Conversely, gaze produced a reversed congruency effect (RCE), with faster identifications on incongruent than congruent trials. To determine the emergence of these gaze-specific attentional mechanisms, 214 Spanish children (4-17 years) divided into six age groups, performed the aforementioned task across three experiments. Results showed stimulus-specific developmental trajectories. Whereas the standard effect of arrows was unaffected by age, gaze shifted from an arrow-like effect at age 4 to a gaze-specific RCE at age 12. The orienting mechanisms shared by gaze and arrows are already present in 4-year-olds and, throughout childhood, gaze becomes a special social cue with additional attentional properties. Besides orienting attention to a direction, as arrows would do, gaze might orient attention towards a specific object that would be attentionally selected. Such additional components may not fully develop until adolescence. Understanding gaze-specific attentional mechanisms may be crucial for children with atypical socio-cognitive development.

Introduction

Undoubtedly, eyes play an essential role in social cognition. From birth, the features of the human visual system allow newborns to attend preferentially to eyes (Farroni et al., 2005; Shultz et al., 2018) and, with time and social experience, gaze will gain certain attentional qualities. As soon as 2 to 5 days old, babies can discriminate between averted and direct gaze, showing a preference for the latter (Farroni et al., 2002a, 2004). A few months later, around the fourth month of life, babies learn to identify gaze direction and use it as an attentional cue (Emery, 2000; Farroni et al., 2002; Frischen et al., 2007; Hood et al., 1998; Vaidya et al., 2011). During the first two years of life, gaze becomes an increasingly specific cue as infants learn not only to follow its direction but also to look for the object the gaze is looking at. For instance, at 6 months, babies can follow their mother's gaze but do not accurately detect the objects she is looking at. In the following months, infants will refine this ability, being able to follow the adult's gaze to look at the gazed at objects within their visual field by 12 months and beyond it by 18 months (Butterworth and Jarrett, 1991). Thus, gaze direction provides important social information about the focus of interest of others, which is central to joint attention. Some of these joint attention acts emerge in the first 6 months of life and continue to develop until 3 years of age (Phillips et al., 2015). Indeed, joint attention has been studied from diverse perspectives, given its importance in socio-cognitive and language development. Although its core definition is present in most articles, i.e., two people attending to the same object or event, some variations have been incorporated in its definition, blending different levels of social attention into the same term (Siposova & Carpenter, 2019). Overall, gaze following is a remarkable milestone in socio-cognitive development, and understanding its underlying attentional mechanisms could be crucial, especially for those children with atypical social development. Therefore, in this study, we aim to explore the specific attentional mechanisms of gaze and their developmental trajectory in childhood.

To understand the particularities of gaze processing, a considerable amount of literature has been conducted with adults comparing gaze to other nonsocial stimuli that also orient attention, such as arrows. Traditionally, gaze and arrows have been compared using standard cueing paradigms, revealing that both stimuli produce analogous effects (Blair et al., 2017; Brignani et al., 2009; Ristic et al., 2002). These results reflect the attentional orienting mechanism that gaze and arrows, as directional cues, have in common (Marotta et al., 2019): both stimuli orient attention in a particular direction where processing is enhanced, leading to similar facilitation effects. Still, gaze generates specific and additional social effects distinct from those shared with arrows. For instance, Ishikawa et al. (2020) showed that affective threatening priming enhanced the gaze cueing effect, but did not influence that observed with arrow cues. Likewise, several social factors modulate the gaze cueing effect, such as the ethnic group membership of the gaze cue (Zhang et al., 2020; for a review, see Dalmaso et al., 2020).

Consistent with early childhood data indicating that gaze becomes an increasingly accurate cue about other people's attentional focus, some experiments have shown a dissociation between arrows and gaze. For instance, Marotta et al. (2012) distinguished two types of attentional selection mechanisms elicited by arrows or gaze cues. In their experiment, adult participants had to detect a target that could appear inside one of two rectangles at either end. A directional cue, a pair of eyes or arrows, was presented at the center of the screen pointing at one rectangle's end. Not surprisingly, both cues produced identical cueing effects: faster detection of cued targets compared to uncued ones (i.e., presented on the opposite rectangle). However, when the target appeared on the opposite end of the cued rectangle, only arrows facilitated target detection (as compared to the similar end of the non-cued rectangle). Arrows seem to direct attention in a general direction, enabling the processing of the whole pointed object. Hence, targets placed anywhere within the object could be rapidly detected. Conversely, gaze directed attention to the specific area of the rectangle at which it is looking. Gaze would not only orient attention but also would fulfill attentional selection at the gazed location. While arrows indicate which direction to attend to, eyes go further, completing the selection of the specific object of attention.

Another distinct aspect of gaze is related to Inhibition of Return (IOR), which comprise a slowing down in the detection of stimuli that appear in pre-cued and, hence, previously attended locations. IOR usually follows a sudden spatial peripheral cue (e.g., a flashlight) that captures attention at a location or object where, after a long enough Stimulus Onset Asynchrony (SOA), a target is presented. Responses to this previously cued location are slower than at other uncued ones. Similar to peripheral cues, gaze can also produce IOR effects but not arrows. By using a central face as a cue, IOR can be found at the gazed location when the SOA is long enough (2400 ms; Frischen & Tipper, 2004) and an intervening event is presented between cue and target (Frischen, Smilek, et al., 2007). However, IOR effects caused by peripheral cues seem to follow a different developmental path than gaze-induced IOR. While 6-month-old infants already present IOR with peripheral spatial cues (Clohessy et al., 1991), gaze-induced IOR emerges at 9 years of age (Jingling et al., 2015). Moreover, Marotta et al. (2013) found that people with Autism Spectrum Disorder (ASD), who exhibit IOR following spatial cues, did not show the effect when it was gaze-induced. These findings could support the hypothesis that distinctive characteristics of gaze direction are based on social aspects, which is precisely the core deficit of people with ASD, a complex neurodevelopmental disorder characterized by social cognition impairments.

Specific gaze properties, as a directional cue, have also been observed at the cerebral level, particularly in the Superior Temporal Sulcus (STS). This area shows specific activation by extracting gaze direction information compared to arrows, non-directional symbolic cues, and even non-directed eye movements (Hooker et al., 2003; Materna et al., 2008). Moreover, STS activity is linked to goal-directed gaze, showing differential activation based on whether gaze is directed at an object (Pelphrey et al., 2003). Experiments along these lines comprised participants observing an avatar who could gaze at an object or an empty spatial location. STS showed increased activation when the avatar looked at the empty location instead of the object. According to the authors, it could reflect a high processing demand caused by the violation of the participant's expectation about the avatar's goal, i.e., to look at the object (Pelphrey et al., 2004, 2005). While this differential activity of the STS is already present in 7 to 10-year-old children (Mosconi et al., 2005), adults with ASD do not show it (Pelphrey et al., 2005). Hence, these results would further support the idea of extra social effects linked to gaze direction.

Within this context, over the last decade, a spatial interference paradigm has clearly and repeatedly dissociated the effects of gaze and arrows (Cañadas & Lupiáñez, 2012; Marotta et al., 2018). In these studies, adult participants had to identify the direction (right or left) signaled by social (gaze) or nonsocial (e.g., an arrow or a triangle) stimuli. The direction indicated by the stimulus could be congruent or incongruent with its location on the screen, so a pair of arrows or eyes displayed on the right, pointing or looking to the right, would constitute a congruent trial; while pointing or looking to the left would constitute an incongruent trial. Thus, unlike studies where gaze is a central cue (e.g. gaze cueing experiments) or acts as an irrelevant distracting stimulus (Ricciardelli et al., 2013), gaze direction constitutes the target in this paradigm, being necessary to process it for the effect to appear (Narganes-Pineda et al 2022). Data has consistently shown that the spatial congruency effect typically found in the literature (faster and more accurate responses to congruent than to incongruent trials) is only produced by nonsocial stimuli like arrows. Surprisingly, the congruency effect was in the opposite direction with gaze, producing faster and more precise responses to incongruent than congruent trials. That is why authors who found the effect for the first time called it Reverse Congruence Effect (RCE) (Cañadas & Lupiáñez, 2012).

The RCE has been repeatedly found using real faces (Cañadas & Lupiáñez, 2012; Jones, 2015; Torres-Marín et al., 2017) or two isolated eyes (Marotta et al., 2018). Despite the robustness of the RCE, its exact nature is not clear. To date, all explanatory hypotheses have been related to social features that gaze but not arrows would possess. For instance, it has been tested with faces expressing emotions (Jones, 2015). Findings replicated the RCE and revealed that the emotion expressed by the looking face could modulate it: the RCE was larger with happy and angry faces than with fearful, sad, or neutral ones. This emotional modulation suggests that the RCE is at least partially rooted in social processes. Moreover, both the effect and its emotional modulation have been investigated in populations with atypical emotional processing, such as individuals with gelotophobia (people with a disproportionate fear of being laughed at by others) (Torres-Marín et al., 2017), and people with high (vs. low) traits of ASD (Marotta et al., 2021). Despite both groups presenting an RCE, no emotional modulation was found in people with high traits of either gelotophobia or ASD, in contrast to people with few traits of gelotophobia or ASD respectively.

Altogether, the evidence suggests that attentional mechanisms shared by directional stimuli may coexist with other additional effects of gaze linked to its social nature. A better comprehension of how and when differences between social and nonsocial stimuli arise might yield new insights into socio-cognitive development. The RCE could be a valuable tool to learn about the attentional particularities of gaze, and tracing its developmental path could be especially useful to understand it. Nevertheless, all the aforementioned RCE studies have been conducted with adults.

Thus, the major goal of this study was to determine how and at which age differences in arrows and gaze processing emerge with this paradigm. In the present study, we aimed at using the spatial interference procedure to measure the RCE as an index of gaze processing maturity. Given the early onset of gaze-following skills, we expected that some differential congruency effects between arrows and gaze (standard for arrows and reversed for gaze) would be already present in preschoolers. However, assuming that social aspects underlie the RCE observed with gaze, its magnitude was supposed to increase with social experience. Consequently, only older children were expected to show an RCE similar to that of adults (Cañadas and Lupiáñez, 2012; Marotta et al., 2018).

Experiment 1

To explore the emergence and development of the effect, four groups of children in consecutive stages of child development (pre-school, middle, and late childhood) were tested. The youngest group of tested children was 4 years old to ensure that they could properly solve the spatial conflict (Bellagamba et al., 2015; Carlson, 2005). Also, at that age, joint attention skills are fully developed (Mundy et al., 2007). From there on, consecutive age groups corresponding to different developmental stages were selected.

Both this and the following two experiments were conducted under the ethical standards of the 1964 Declaration of Helsinki (last update: Seoul, 2008), as part of a larger research project which has been positively evaluated by the University of Granada Ethical Committee (175/CEIH/2017).

Method

Participants

We collected data from 103 typically developing children belonging to four different age groups: 4, 5, 6, and 10 years of age (see sample descriptives in Table 1). Families were reached through two primary charter schools, and signed informed consent and assent to participate in the study were obtained from parents and children, respectively. Seven children performed the experimental task in the laboratory during a school visit, and the rest of them conducted it at their school in a separate room reserved for the study; all under similar experimental conditions. Children who wanted to participate were taken to a well-lit and quiet room equipped with a table, a chair, and a computer. The exclusion of participants was based on information from parents and teachers. The exclusion criteria were having any psychological or neurological disorders, including autism spectrum disorder, intellectual disability, attention-deficit/hyperactivity disorder, or dyslexia. Once the task was completed, we offered a sticker or a stamp to the child as a reward for their participation.

A minimum sample size of 20 participants per group was decided according to a priori power analysis using the software GPower (Faul et al., 2007). We took the effect size obtained in Marotta (2018), $\eta^2_P = .54$, as a reference for the critical Target Type x Congruency interaction for which we wanted to investigate its developmental time course, assuming a significance level of .05 and a power of .95. This analysis showed that a minimum of 8 participants per group was necessary for it to show a significant interaction. Given that we expected the effect to be weaker in younger children, we collected data from a minimum of 20 participants per group. In this experiment and all the following ones, data from participants for whom for any reason less than 24 trials per condition were available, and data from participants who did not achieve at least 60% overall accuracy (being 50% chance level), were eliminated from the total sample (4.8%) prior to any analysis. After exclusions, 22, 24, 27, and 25 children remained in each age group of 4, 5, 6, and 10, respectively.

Table 1

Sample Descriptives in Experiments 1 and 2

Grades	N	Mean age in years (SD)	Male	Female
2° grade of infant education	22	4.2 (.43)	9	13
3° grade of infant education	24	5.3 (.48)	14	10
1° grade of primary school	27	6.2 (.42)	15	12
5° grade of primary school	25	10.5 (.51)	10	15
1° grade of secondary school	60	12.5 (.50)	31	29

Note. The school grades correspond to the Spanish educational system.

Apparatus and stimuli

The experimental task was designed and run by using E-prime 2.0. This software allows us to control stimulus presentation, timing, and data collection. All stimuli were presented on a standard personal computer with a 562 x 735-pixel resolution.

Since the RCE has been found with both isolated eyes and faces (Cañadas & Lupiáñez, 2012; Marotta et al., 2018), we presented full faces to make the task engaging for children. Stimuli comprised two full-color photographs, one female and one male, looking to the right or left with a neutral emotional expression, and two horizontal black arrows also pointing to the right or the left (see stimulus examples in Figure 1a). Face stimuli were obtained from the Karolinska Directed Emotional Faces (images id AM25NES and AF21NES) (Lundqvist et al., 1998) and eyes directions were modified with Adobe Photoshop CS6. The main criteria for selecting these two specific faces for this study was how clearly gaze direction could be detected (i.e., because of the size and shape of the eyes). Both faces and arrows had been previously used in studies with the same paradigm (e.g., Marotta et al. 2020).

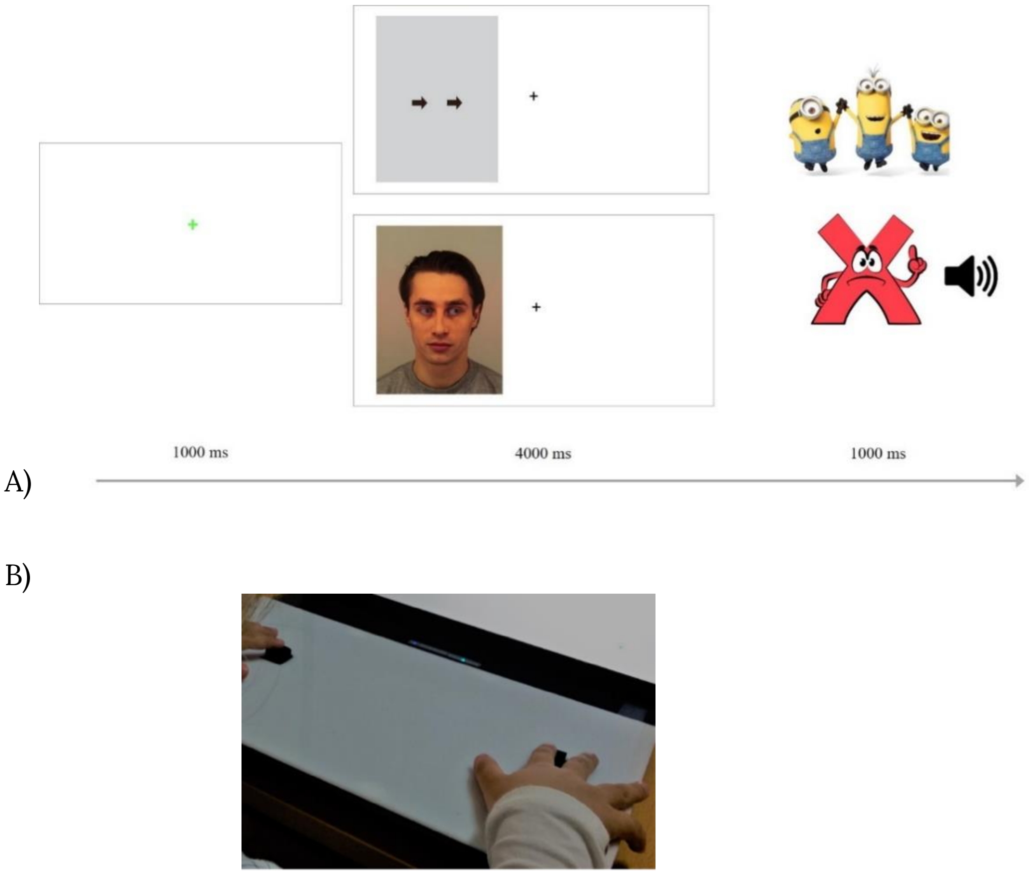
Procedure

We closely followed the procedure of preceding studies (Cañadas & Lupiáñez, 2012; Marotta et al., 2018) with some modifications to adapt the task to age-related special requirements. Children were seated approximately 60 cm from the computer screen with the experimenter placed next to them. As in previous studies, they had to discriminate, as fast and accurately as possible, to which direction (right or left) faces or arrows were looking at or pointing by pressing either the left or the right key on the keyboard ("z" and "up arrow", respectively) with their corresponding hand. Those keys were selected because they were symmetrically separated on the keyboard of the computer used.

As illustrated in Figure 1a, trials began presenting a colored central cross as a fixation point during 1000 ms. Then, the target was presented until a response was given or until 4000 ms if no response was emitted (2000 ms in Marotta et al., 2018). Unlike Marotta et al. (2018), the target type was presented randomly on a trial-by-trial basis, so that either a face or a pair of arrows could appear on each trial. This decision was based on previous studies (Narganes-Pineda et al., 2020) in which the RCE was found with a within-block manipulation of stimuli presentation. We used the within-block task design since finding the RCE under these conditions, i.e., participants responding randomly to one of two stimuli, would indicate a sufficiently robust effect to occur even on a trial-by-trial basis. Each target could appear to the left or the right of the central fixation point, and they could look at or point to either side, creating two congruency conditions: congruent trials in which both location and direction matched (e.g., two arrows on the left pointing to the left), and incongruent trials in which they did not (e.g., two arrows on the left pointing to the right).

Figure 1

Schematic Representations of the Experimental Procedure.



Note. Panel A: Representation from left to right of the sequence of an incongruent trial of each Target Type. The male face (ID: AM25NES) was obtained from Karolinska Directed Emotional Faces (Lundqvist et al., 1998). Minions cartoons were one of the eight cartoons used as feedback for the 4- and 6-year-olds. They were displayed after the correct answers in the practice block and during breaks in the experimental block. Instead, children over 6 years of age watched a cartoon of an okay hand gesture. The red letter “x” was used both in practice and experimental blocks as feedback after an incorrect response for the entire sample. The speaker icon represents auditory feedback. Panel B: Picture of the polypropylene board used to cover the keyboard of 4 to 6 years-old children on Experiments 1 and 3.

First, a practice block was conducted with eight trials randomly selected from the different trial types, each of them followed by 1000 ms audio-visual feedback. After hits, one out of eight cartoon characters appeared accompanied by a pleasant sound. After incorrect responses, a cartoon of a red-letter X appeared together with a failure sound. In case the practice block was insufficient to understand the task, it could be repeated.

After practice, children performed 128 trials (64 per target type) divided into four identical experimental blocks. During these blocks, only the error feedback was provided to make the task as efficient as possible. However, a display with a randomly appearing cartoon character and a pleasant sound was presented every 16 trials. These pauses, especially in the youngest children, proved to be essential to encourage them to continue by seeking to see the remaining characters and to rest for as long as the experimenter considered necessary. Since the feedback was age-adjusted, it had to be slightly changed for the 10-year-old group. Cartoons might be too childish for the older participants, leading to a lack of motivation or rejection of the task. To prevent that, a simple sketch of a hand making an "okay" gesture replaced cartoon characters. Besides, they had pauses every 32 instead of 16 trials.

It is important to note that a certain level of finger movement control is required to select and press a particular key on a computer keyboard. For preschoolers, this may be an added and unrelated difficulty. To avoid these potential problems, for children from 4 to 6 years old, we covered the keyboard with a manufactured white polypropylene board that only exposed the two corresponding response keys (see Figure 1b). In addition, we inserted a square black foam rubber into each hole to facilitate access to the actual key, which was a few millimeters below the board. On the one hand, these adaptations facilitated the display and selection of the correct key, avoiding possible errors due to difficulties with fine motor skills. On the other hand, it also allowed children to rest their hands on the laptop without unintentionally pressing other keys.

Design

We used a 2 (Target Type: arrows vs. gaze) x 2 (Congruency: congruent vs. incongruent) x 4 (Age group: 4, 5, 6, and 10 years old) mixed factor design. Age was manipulated between participants, while the other two variables were manipulated within participants. Both reaction time (RT; in ms) and the percentage of errors were used as dependent variables.

Results

All statistical analyses for the current experiment and the two subsequent ones were conducted with the free statistical package JASP software version 1.12. for Windows. The level of significance was set at 0.05.

A repeated measure analysis of variance (ANOVA) was carried out for each of the dependent variables: RT and accuracy (percentage of errors). In both cases, Age (4, 5, 6 and 10 years) was treated as a between-participants factor and Congruency (congruent vs. incongruent) and Target Type (arrows vs. gaze) as within-participants ones.

For the RT analysis, incorrect responses (10%) were not considered. To prevent extreme scores from biasing our conclusions, trials that exceeded three standard deviations of the average mean in each group were also excluded; thus, this criterion was customized for each group of age eliminating 10%, 6%, 5%, and 4% of trials, respectively for the groups of 4, 5, 6 and 10-year-olds. Means and SDs of both dependent variables for each experimental condition are presented in Table 2.

The ANOVA performed on mean RTs revealed a main effect of Age ($F(3, 94) = 88.33$, $p < .001$, $\eta^2_P = .74$). A post-hoc Bonferroni test showed significant differences between all groups, proving that children became progressively faster as age increased (1501, 1253, 1045 and 724 ms of overall RT arranged in ascending order of age), with large differences between groups.

Data for errors rate were consistent with those of the RT showing a main effect of Age ($F(3, 94) = 18.04$, $p < .001$, $\eta^2_P = .37$). Post-hoc Bonferroni comparisons revealed that 4-years-old children made many more errors than the rest of the groups. Error rate decreased in subsequent age groups with no significant differences between 5 to 6 and 6 to 10 years old (20, 10, 5, and 2% arrange in ascending order of age).

Table 2

Mean RTs in ms and Percentage of Error of the Five Age Groups as a Function of Congruency and Target Type in Experiment 1.

Age Group	Arrow				Gaze			
	Congruent		Incongruent		Congruent		Incongruent	
	RT	% error	RT	% error	RT	% error	RT	% error
4	1350 (212.44)	7.86 (8.53)	1473 (246.44)	25.89 (16.21)	1531 (247.93)	15.60 (17.14)	1649 (276.98)	26.70 (21.63)
5	1095 (242.79)	8.33 (12.56)	1237 (245.27)	16.67 (10.97)	1321 (238.81)	6.12 (7.46)	1360 (224.87)	11.46 (10.16)
6	921 (125.36)	3.70 (8.13)	1000 (126.96)	7.18 (7.93)	1128 (182.15)	3.94 (6.16)	1131 (152.03)	7.52 (9.10)
10	643 (80.16)	0.38 (1.37)	693 (82.11)	2.79 (3.05)	785 (71.49)	2.00 (2.84)	775 (81.23)	4.04 (4.18)

Note. Standard deviations are shown in parentheses. These pure values of RT and error rate were transformed into proportional values for the statistical analysis. RT = reaction time for correct responses.

As might be expected, data obtained from pure RT and error rates revealed large group differences in overall speed and accuracy. These age-related improvements in ability level could lead to a problematic interpretation of the process of interest (Draheim et al., 2019; Hedge et al., 2018). For instance, an overall reduction in the RT could mask how significant the congruency effect is over age. In order to be able to make proper groups comparisons, means RTs were transformed into proportional RT, a commonly used RT transformation in studies based on age-related differences (Bialystok et al., 2008; Bruin de & Sala, 2018; Colcombe et al., 2005). For each participant, the mean RT of each experimental condition was divided by their overall reaction time, so that any condition differences should be interpreted based on the participant's average responses. In other words, proportional RT values for each condition represent how much slower or faster the participant responded in relation to their overall RT. For example, a proportional RT of 0.5 would mean that participant was 50% faster answering on that condition compared to their task's average RT. Contrary, a proportional RT of 1.5 would mean that the participant was 50% slower on that condition. The same transformation was applied to error rate values. Henceforward, all analyses were performed with proportional RT and error rates as dependent variables.

Proportional Reaction Time

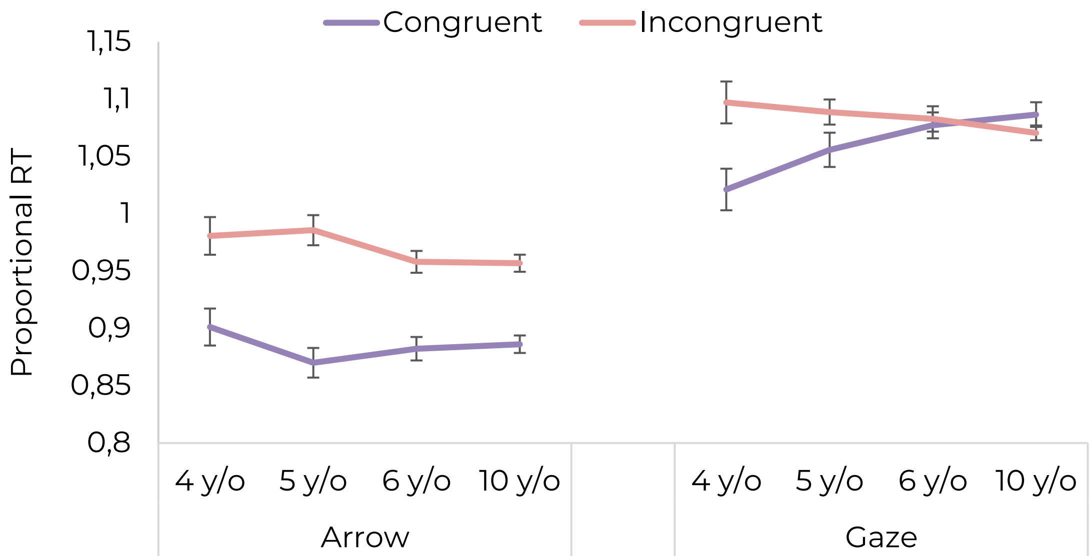
For proportional RTs, the ANOVA reported the main effects of Target type ($F(1, 94) = 250.72$, $p < .001$, $\eta^2_P = .73$) and Congruency ($F(1, 94) = 69.20$, $p < .001$, $\eta^2_P = .42$). Participant responses to arrows were 16% faster than to gaze, and 4% faster to congruent than to incongruent trials. A significant Congruency x Target Type interaction was also found ($F(1, 94) = 35.7$, $p < .001$, $\eta^2_P = .28$), as well as a Congruency x Age interaction ($F(3, 94) = 3.51$, $p = .018$, $\eta^2_P = .10$). Most importantly, the analysis revealed a significant three-way Target Type x Congruency x Age interaction ($F(3, 94) = 3.38$, $p = .021$, $\eta^2_P = .10$). Separate ANOVAs for each Target Type were performed to further understand their interactive effects.

For arrows, just a significant main effect of Congruency ($F(1, 94) = 131.06$, $p < .001$, $\eta^2_P = .58$) independently of age ($F(3, 94) = 1.03$, $p = .383$, $\eta^2_P = .03$) was found. As observed in Figure 2, all groups showed a significant standard congruency effect, so all participants responded faster to congruent than incongruent trials.

Unlike arrows, the gaze's congruency effect changed with age ($F(3, 94) = 4.51$, $p = .005$, $\eta^2_P = .13$). As displayed in Figure 2, 4-year-olds presented a standard congruency effect ($F(1, 21) = 9.07$, $p = .007$; $\eta^2_P = .30$) that disappeared over the subsequent groups. While 4-year-old children showed an identical effect regardless of Target Type ($F(1, 21) < 1$), a clear Congruency x Target Type was observed in the oldest group ($F(1, 24) = 51.01$, $p < .001$, $\eta^2_P = .68$). It should be noted that at the age of 10, the congruency in response to the gaze was reversed, although not significantly ($F(1,24) = 1.35$, $p = .25$, $\eta^2_P = .053$).

Figure 2

Proportional Reaction Time (RT) as a Function of Congruency for Each Target Type and Age Group in Experiment 1.



Note. A proportional RT equal to 1 represents the average RT. Values above or below this number would indicate faster or slower responses respectively related to the average. Errors bars represent the standard error of the mean.

Proportional Error Rates

For the proportional error rate, the ANOVA revealed a main effect of Congruency ($F(1,94) = 76.15$, $p < .001$, $\eta^2_P = .45$). Children committed fewer errors on congruent than on incongruent trials. No other main effects were found. However, the Target Type x Age interaction was significant (F(3, 94) = 5.06, p = .003, η^2_P = .14), finding that while 5-year-old children had a higher error rate responding to arrows than to gaze, the opposite pattern was found in the oldest group. None of these differences were found in the two remaining groups. Congruency by Target type interaction was likewise statistically significant (F(1, 94) = 4.69, p = .033, η^2_P = .05), showing that arrows had a larger congruency effect than gaze, both in the standard direction. Neither the Age x Congruency interaction (F(3, 94) < 1), nor the three-way interaction of Age, Congruency, and Target Type (F(3, 94) < 1) were significant.

Discussion

Once again, evidence shows differences in attentional processing based on the social or nonsocial nature of the target. First, gaze produces a slowdown in overall RT compared to arrows. According to previous literature, it could indicate deeper and more complex processing of gaze (Hietanen et al., 2006). It is noteworthy that the two stimuli display a completely different developmental trajectories. Despite slightly decreasing over age, the arrow's congruency effect remains similar in all age groups, so that all children respond faster to congruent than to incongruent trials. Conversely, gaze switches from a significant standard congruency effect at age 4 to no effect from age 5 to 10.

Data from error rates do not show differential effects between stimuli, revealing a general standard congruency effect. Considering that the experimental task is quite simple and that several subjects do not make a single error, the error rate could be a less sensitive measure than RT to capture the effects at hand.

Experiment 2

Whatever its nature, the RCE has proved to be a robust effect widely replicated in the adult population (Cañadas & Lupiáñez, 2012; Jones, 2015; Marotta et al., 2018, 2019; Torres-Marín et al., 2017). It is therefore surprising that, even though the RCE becomes noticeable at 10, it still does not reach significance. To complete the developmental trajectory of the effect on late childhood, an older group of 12-year-old children performed the task in this experiment.

Method

Participants

Here, we collected data from a group of 60 typically developing 12-year-old children whose families were also reached from one school of our first experiment (see sample descriptives in Table 1). Again, signed informed consent and assent to participate were obtained from parents and children, respectively. The exclusion criteria were the same as in Experiment 1. This group performed the task during a scheduled school visit to our lab under identical experimental settings as previous groups. Although we aimed at testing 20 participants per group (see Experiment 1), all children visiting the center were invited to take part in the experiment.

Procedure

Both stimuli and procedure were identical to Experiment 1. As for the 10-year-old group of Experiment 1, the task was subtly adapted to make it less childish by modifying the visual feedback and removing the keyboard cover.

Results

Table 3 displays RT and error rate values. For subsequent ANOVAs, both were transformed into proportional scores. No participants were excluded for not meeting the criteria of accuracy or the minimum number of trials. One repeated measure ANOVA for each dependent variable (proportional RT and proportional error rates) was conducted for this group with Congruency (congruent and incongruent) and Target type as two within-participants variables. As in the first experiment, incorrect responses (3%) and extreme RT values trials (2%) were excluded from de RT analysis.

Table 3

Mean RTs in ms and Percentage of Error as a Function of Congruency and Target Type in Experiment 2.

Age Group	Arrow				Gaze			
	Congruent		Incongruent		Congruent		Incongruent	
	RT	% error	RT	% error	RT	% error	RT	% error
12	613 (82.18)	0.73 (2.26)	628 (79.85)	2.60 (4.12)	725 (78.32)	3.75 (5.07)	706 (82.32)	4.58 (5.99)

Note. Standard deviations are shown in parentheses. These pure values of RT and error rate were transformed into proportional values for the statistical analysis. RT = reaction time for correct responses

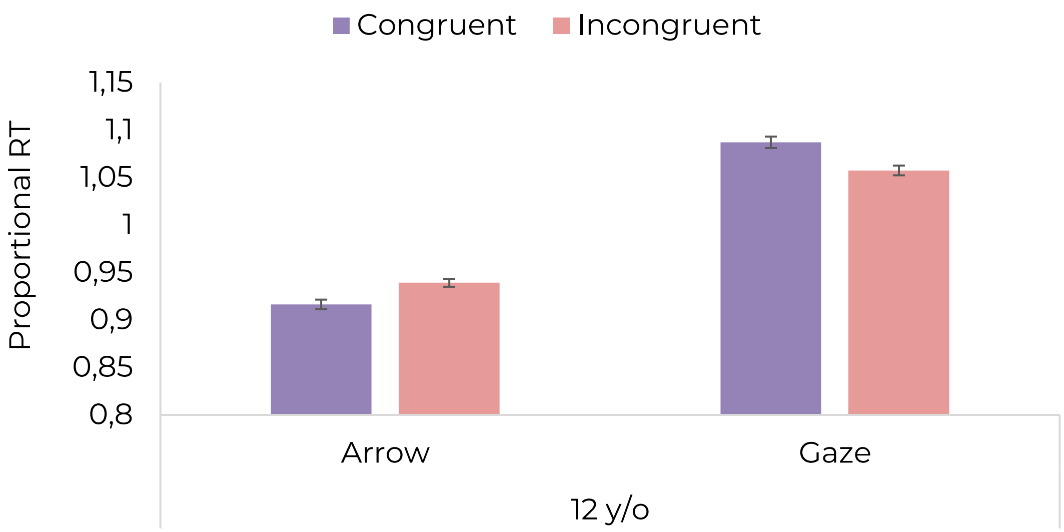
Proportional reaction time

The ANOVA performed on proportional RT revealed a main effect of Target Type ($F(1, 59) = 508.73$, $p < .001$, $\eta^2_P = .90$), responses being 16% faster to arrows than to gaze. No main effect of Congruency was found in this group ($F(1, 59) < 1$). Importantly, however, the Target type x Congruency interaction was significant ($F(1, 59) = 28.39$, $p < .001$, $\eta^2_P = .33$). As shown in Figure 3, arrows generated a significant standard congruency effect ($F(1, 59) = 11.35$, $p = .001$, $\eta^2_P = .16$) with 3% faster responses to congruent than to incongruent trials. On the contrary, gaze produced a significant reversed congruency effect ($F(1, 59) = 10.14$, $p = .002$, $\eta^2_P = .15$) with 5% slower responses to congruent than to incongruent trials.

It is worth noting that Experiment 2 had a larger sample size than any of the groups of Experiment 1. To verify whether data would be reproduced with a similar number of participants as in Experiment 1, we performed an additional bootstrapping analysis using R Statistical Software (R Core Team, 2021). We used bootstrapping (100 iterations) to randomly select smaller subsamples of 25 participants with replacement from the full sample of 60 (see Bernoster et al., 2019 for a similar example of bootstrapping analysis). This specific number of participants was selected for being the average sample size of the four groups of Experiment 1. Bootstrapping yields an overview of the number of significant results (based on a significant level of 5%) that would have been got with smaller samples across 100 iterations. Data showed 95% of significant Congruency x Gaze interaction and 44% of significant gaze's RCE. Additionally, based on a binomial likelihood function, we estimated the probability of finding those percentages of significant results (out of 100 iterations) given H1 or H0 were true (Lakens & Etz, 2017). Assuming an α = .05 and 1-β=.80, we obtained a likelihood ratio of 1.22 x 10^{15}, which indicates that our 44% of significant results is 1.22 x 10^{15} times more likely when H_1 is true than when H_0 is true. This analysis shows that similar results would have been observed in Experiment 2 with a sample size similar to that of each group in Experiment 1.

Figure 3

Proportional Reaction Time as a Function of Congruency for Each Target Type on 12-Year-Old from Experiment 2.



Note. A proportional RT equal to 1 represents the average RT. Values above or below this number would indicate faster or slower responses respectively related to the average. Errors bars represent the standard error of the mean.

Proportional error rates

The ANOVA performed on proportional error rates revealed a main effect of Target Type ($F(1, 59) = 14.61$, $p < .001$, $\eta^2_p = .20$), participants committing more errors responding to gaze than to arrows, and a main Congruency effect ($F(1, 59) = 5.62$, $p = .02$, $\eta^2_p = .09$), showing a standard congruency effect. No significant interaction was found ($F(1, 59) = 2.67$, $p = .11$).

Discussion

RT data show that 12-year-old children, like younger groups from Experiment 1, manifest a standard congruency effect responding to arrows. However, this group is the only one with a significant RCE responding to gaze. Although the effect of gaze differs from that of arrows from the age of 5, an adult-like RCE does not emerge until the age of 12. Again, the error rate does not seem to capture differences in the congruency effect, showing an overall standard effect.

In short, the differential effect between arrows and gaze, previously found in the adult population (Cañadas & Lupiáñez, 2012; Marotta et al., 2018), appears for the first time in 12-year-olds. Considering the social relevance of gaze from infancy, 12 years of age could be a relatively late age for the RCE to emerge. In this regard, the absence of differences between arrows and gaze displayed by 4-year-olds could be even more surprising. The intermixed way in which arrows and gaze were presented might have affected the lack of RCE observed in the youngest children. In the literature with adult populations, the paradigm has been carried out mostly by presenting the two stimuli separated into counterbalanced blocks (Cañadas & Lupiáñez, 2012; Marotta et al., 2018). On each block, participants responded to a single type of stimulus. However, as explained above, the RCE has also been found with a within-block manipulation of the target type, like in Experiments 1 and 2, with both stimuli being randomly presented within the same block of trials (Hemmerich et al., 2022). Although the effect is unaffected by stimulus presentation with adults, besides the effect being larger with the between-block than the within-block manipulation, it has not been tested with children to date. Particularly in groups of younger children, the absence of RCE may be due to task-context effects rather than gaze-related developmental changes. The youngest children may need a longer exposition to gaze, i.e., more consecutive gaze trials, to show the reversion in the congruency effect.

Experiment 3

To ensure that our findings were not due to the mixed presentation of the two stimuli type, we replicated the task using a between-block manipulation. In Experiment 3, two groups of children and one group of adolescents performed the task responding to stimuli in two separate blocks in a counterbalanced order.

Method

Participants

A total sample of 57 typically developing participants was recruited from both the same pool as in Experiment 1 and a high school. In this experiment, groups were composed of three different ages: 4, 6, and 17 years old (see sample descriptives in Table 4). As in the previous experiments, signed informed consent and assent to participate in the study were obtained from families and participants, respectively. The same exclusion criteria as in the two previous experiments were maintained.

Table 4

Sample Descriptives of Participants in Experiment 3

Grades	*N*	Mean age in years (*SD*)	Male	Female
2° grade of infant education	15	3.9 (.26)	9	6
1° grade of primary school	21	6.4 (.54)	15	6
1° grade of high school	20	17 (.65)	2	18

Note. The school grades correspond to the Spanish educational system.

Procedure

Groups of 4- and 6-years old children performed the experiment at their school, while teenagers carried it out in the lab during a programmed school visit.

All equipment, task, and stimuli were identical to the two previous experiments, including feedback and keyboard modifications for both older (17-year-olds) and younger groups (4- and 6-year-olds). Nevertheless, stimuli were presented in two separate and counterbalanced blocks of 64 trials each, headed by their corresponding practice block of 8 trials.

Design

A 2 (Congruency: congruent, incongruent) x 2 (Target Type: arrow, gaze) x 3 (Age: 4, 6, 17 years-old groups) design was performed with Congruency and Target Type as within-participants factors and Age as a between-participants one. Again, the dependent variables were proportional RT and proportional error rate.

Results

Table 5 displays RT and error rate values. Again, both were transformed into proportional scores for subsequent ANOVAs. A repeated measure ANOVA was carried out for each of the dependent variables. In this case, just one participant from the 4-year-old group was eliminated from the sample (1.7%) before analysis for not meeting the accuracy criteria.

Once again, incorrect responses (8.5%) were not considered for RT analysis. Extreme scores were also excluded under the same aforementioned criteria, eliminating 11, 6, and 3% of trials for the 4, 6- and 17-year-old groups, respectively.

Table 5

Mean RTs in ms and Percentage of Error of the Three Age Groups as a Function of Congruency and Target Type in Experiment 3.

	Arrow				Gaze			
	Congruent		Incongruent		Congruent		Incongruent	
Age Group	RT	% error	RT	% error	RT	% error	RT	% error
4	1253 (274.97)	5.67 (5.60)	1435 (258.66)	20.51 (17.96)	1410 (242.53)	6.84 (10.51)	1488 (226.54)	15.43 (17.09)
6	989 (249.4)	7.89 (10.57)	1047 (199.68)	15.63 (15.00)	1049 (145.07)	2.53 (3.68)	1106 (139.88)	5.95 (7.40)
17	535 (107.8)	1.56 (2.90)	565 (102.8)	6.09 (5.72)	602 (87.71)	2.50 (3.82)	561 (112.63)	3.28 (3.95)

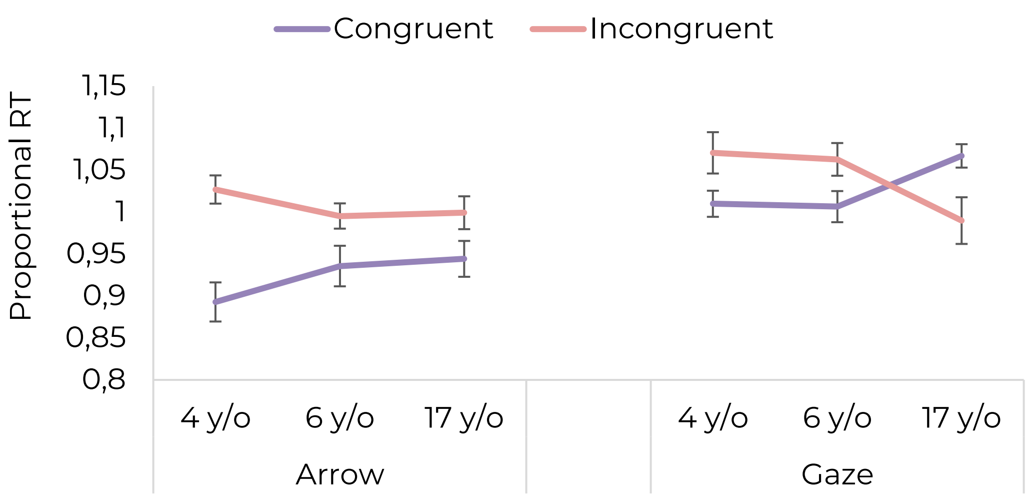
Note. Standard deviations are shown in parentheses. These pure values of RT and error rate were transformed into proportional values for the statistical analysis. RT = reaction time for correct responses.

Proportional reaction time

The ANOVA showed a main effect of Target Type, $F(1,53) = 11.31$, $p = .001$, $\eta^2_P = .18$, responses being 8% faster for arrows than for gaze, and a main effect of Congruency, $F(1, 53) = 25.58$, $p < .001$, $\eta^2_P = .33$, responses being 4% faster on congruent than on incongruent trials. Moreover, a significant interaction between Congruency and Age, $F(2, 53) = 10.85$, $p < .001$, $\eta^2_P = .29$, as well as Congruency and Target Type, $F(1, 53) = 16.9$, $p <.001$ $\eta^2_P = .24$, were found. More importantly, all three factors interacted significantly ($F(1, 53) = 5.43$, $p =. 007$, $\eta^2_P = .17$). Separate ANOVAs for each Target Type were performed, revealing similar results to Experiment 1. As clearly illustrated in Figure 4, arrows produced a significant standard congruency effect across the three age groups. Although Congruency interacted significantly with Age (F(2, 53) = 3.78, p = .029, η^2_P = .13), the effect being larger at age 4 than at 6 or 17, the standard effect was observed in the three groups (all ps < .05). Gaze analysis also showed a significant Congruency x Age interaction (F(2, 53) = 12.8, p < .001, η^2_P = .33). However, in contrast to arrows, and consistent with the two previous experiments, whereas 4- and 6-year-olds had a standard congruency effect, F(1, 14) = 4.97, p = .04, η^2_P = .26 and F(1, 20) = 8.13, p = .01, η^2_P = .29, respectively, only adolescents showed the RCE (F(1, 20) = 13.5, p = .002, η^2_P = .42).

Figure 4

Proportional Reaction Time (RT) as a Function of Congruency for Each Target Type Among Age Groups in Experiment 3.



Note. A proportional RT equal to 1 represents the average RT. Values above or below this number would indicate faster or slower responses respectively related to the average. Errors bars represent the standard error of the mean.

Proportional error rates

The analysis of proportional error rates showed significant main effects of Target Type ($F(1, 53) = 10.71$, $p = .002$, $\eta^2_P = .17$) and Congruency ($F(1,53) = 44.74$, $p < .001$, $\eta^2_P = .46$), committing more errors responding to arrows than to gaze (9.35% vs. 5.70%), and responding to incongruent than congruent trials (10.66% vs. 4.39%). The only significant interaction was Target Type x Congruency ($F(1,53) = 13.55$, $p < .001$, $\eta^2_P = .20$), being the congruency effect larger for arrows than for gaze.

Discussion

Findings from Experiment 3 replicate the main results of the two prior experiments. Again, while all groups present a standard congruency effect responding to arrows, the effect of gaze changes across age groups. Opposite effects are observed in the youngest and the oldest group of children: a standard congruency effect on 4-year-olds and the RCE on 17-year-olds. Thus, the age-related differences only observed for eye gaze seem to be independent of stimuli presentation (within vs. between blocks).

However, data from 6-year-old children differ from the age equivalent group in Experiment 1, as a standard congruency effect was observed also for gaze in this group. The between-block manipulation of stimuli could have improved the signal-to-noise ratio, as children were exposed to the same stimulus across trials. In addition, the potential attentional demands of an intermixed presentation, such as shifting the attentional focus on different perceptual features from trial to trial (Jaswal & Logie, 2013), would be diminished. In any case, data from both Experiments 1 and 3 agree that gaze produces the same effect as arrows in 4-year-olds, no matter whether the two stimuli are presented in different blocks of trial or mixed within the same block. Importantly, the RCE, a critical signal of mature processing of gaze, does not appear until late childhood. Thus, the response to gaze would change from the preschool years onwards, possibly mediated by further development of specific gaze-related attentional qualities that will ultimately lead to the RCE. Those mechanisms, e.g., gaze quality to direct attention to a specific object that will be attentively selected, could be immature in 6-year-olds, who would therefore exhibit for gaze an inconsistent pattern of either no effect or an arrow-like standard effect.

It should be mentioned that, even though the RCE is clear in adolescents from Experiment 3, they were not age-matched to the sample of Experiment 2. Nevertheless, since 12-year-olds showed the RCE even with an intermixed presentation of stimuli, they would probably also show it with a blocked one, where the consecutive presentation of the same stimulus would increase effect size (e.g., see Marotta et. al. 2018, for a between-block manipulation, and Hemmerich et al., 2022, for a within-block one).

General Discussion

Gaze provides essential information for socio-cognitive development. From a very early age, it acts as a cue to infer the interests, behaviors, thoughts, and emotions of social partners. However, as a directional stimulus, it shares attentional orienting properties with other nonsocial stimuli, such as arrows (Brignani et al., 2009; Marotta et al., 2019). Therefore, to investigate the specific processing of gaze, it is important to use appropriate paradigms to dissociate the processing of social orienting cues from that of nonsocial ones. Segregating the singular effects of gaze from those shared with nonsocial directional stimuli will shed light on the role of gaze on cognitive development.

In this line, the core aim of our study was to determine how and when additional social components of gaze arise by tracking arrows and gaze differences across ages. In particular, we looked for the emergence of the reversed congruency effect (RCE) typically observed with gaze, in contrast to arrows. Results show a completely different developmental path of the congruency effect observed with each stimulus type. The standard congruency effect of arrows remains stable from childhood to early adolescence. Conversely, the effect of gaze changes drastically throughout this period, being indistinguishable from the effect of arrows in 4-year-old children and disappearing from 5 to 10 years of age (Experiment 1). From the age of 5, gaze could progressively gain specific attentional properties that would eventually lead to an RCE at age 12, as observed in Experiment 2. Furthermore, and importantly, these results are not affected by stimuli presentation since a similar pattern of data was observed both by presenting gaze and arrows randomly on a trial-by-trial basis (Experiments 1 and 2) and by presenting them separated into different blocks of trials (Experiment 3).

Our results are in line with the developmental course of other gaze-specific effects described above, such as gaze-induced IOR. Indeed, Jingling et al. (2015) showed that in 6-8-year-olds, in contrast to older children, a central gaze just triggered facilitatory cueing effects, but no IOR. It is not until the age of 9 that gaze-induced IOR emerged. In addition, this absence of gaze-induced IOR has been found in people with Asperger (Marotta et al., 2013), whose main deficits are related to social cognition. Similarly, the RCE could reflect a more socially advanced gaze-related mechanism, which would develop during the preschool years and culminate in early adolescence. Interestingly, a recent ERP study (Marotta et al., 2019) showed that gaze and arrows produce similar congruency effects on early components (P1, N1, and N70) and opposite congruency effects on later ones (N2 and P300). This pattern of data fits nicely with the idea that gaze and nonsocial stimuli share a similar attentional orienting mechanism, as generally observed with the gaze cueing paradigm (Brignani et al., 2009), but gaze contributes to performance by triggering additional social mechanisms that could develop during childhood. However, it is unclear what social attentional properties gaze but not arrows acquired during this period.

One possibility could be that gaze develops the ability to not only guide attention but to select the object or event to which it is directed. This property of gaze, apparent from early infancy, may become entrenched with age and social experience, eventually producing an extra effect that would lead to the RCE. This hypothesis is consistent with data from Marotta et. al. (2012) who found that arrows guided attention in a broad and unspecific direction, while gaze also focused it on the specific location that had been looked at. Indeed, this is actually what happens in an episode of joint attention which involves following another person's gaze toward their point of interest.

Actually, the RCE could be explained similarly. According to Edwards et al. (2020), in incongruent trials, the eye gaze looks jointly with the participant towards the central fixation point. This "joint gaze" would lead to an attentional selection of the fixation point and, therefore, quick identification of gaze direction. This would counteract the standard congruency effect also triggered by gaze (Marotta et al, 2019) to ultimately lead to the observed RCE. Indeed, it has been shown that the reversed congruency effect observed with gaze is enhanced by reducing spatial interference (Roman-Caballero et al., 2021). Alternatively, on congruent trials, gaze goes outward where no object can be selected. Participants would follow it towards a potential target, even if gaze is irrelevant to the task at hand. This would produce a kind of "joint distraction" (Hemmerich et al., 2022) as gaze would induce participants to look for the potential object to select, leading to the slower RT observed for gaze congruent trails in adolescents, where there is no object to gaze at, compared to incongruent trials, where gaze look at the fixation point where participants are also gazing at. Again, this socially induced slowdown would counteract the spatial congruency effect, leading to slower rather than faster responses on congruent trials. Indeed, as observed in our Experiments 1 and 3, gaze and arrows produced a similar standard congruency effect in 4-year-old children. Whereas preschool children already show the attentional orienting mechanisms shared by both stimuli, which are in line with previous studies (Ristic et al., 2002), the additional social mechanisms triggered by gaze can still be unlearned or immature. In our opinion, this makes unlikely a joint attention-based explanation of the RCE, as joint attention is supposed to be fully developed at age 4 (Phillips et al., 2015). Further attentional selection effects generated by gaze, referred to as joint distraction, may require more time to become established. From the age of 5, as age and social experience increase, the attentional act of gaze would become more specific and complete, eventually leading to a "joint distraction effect" and, therefore, to the RCE. This process will peak in early adolescence, a period with notable social changes.

Both our results and the suggested explanation fit with the brain developmental course of gaze-related areas, such as the STS. This area, which shows specific activation extracting directional information from goal-directed gaze

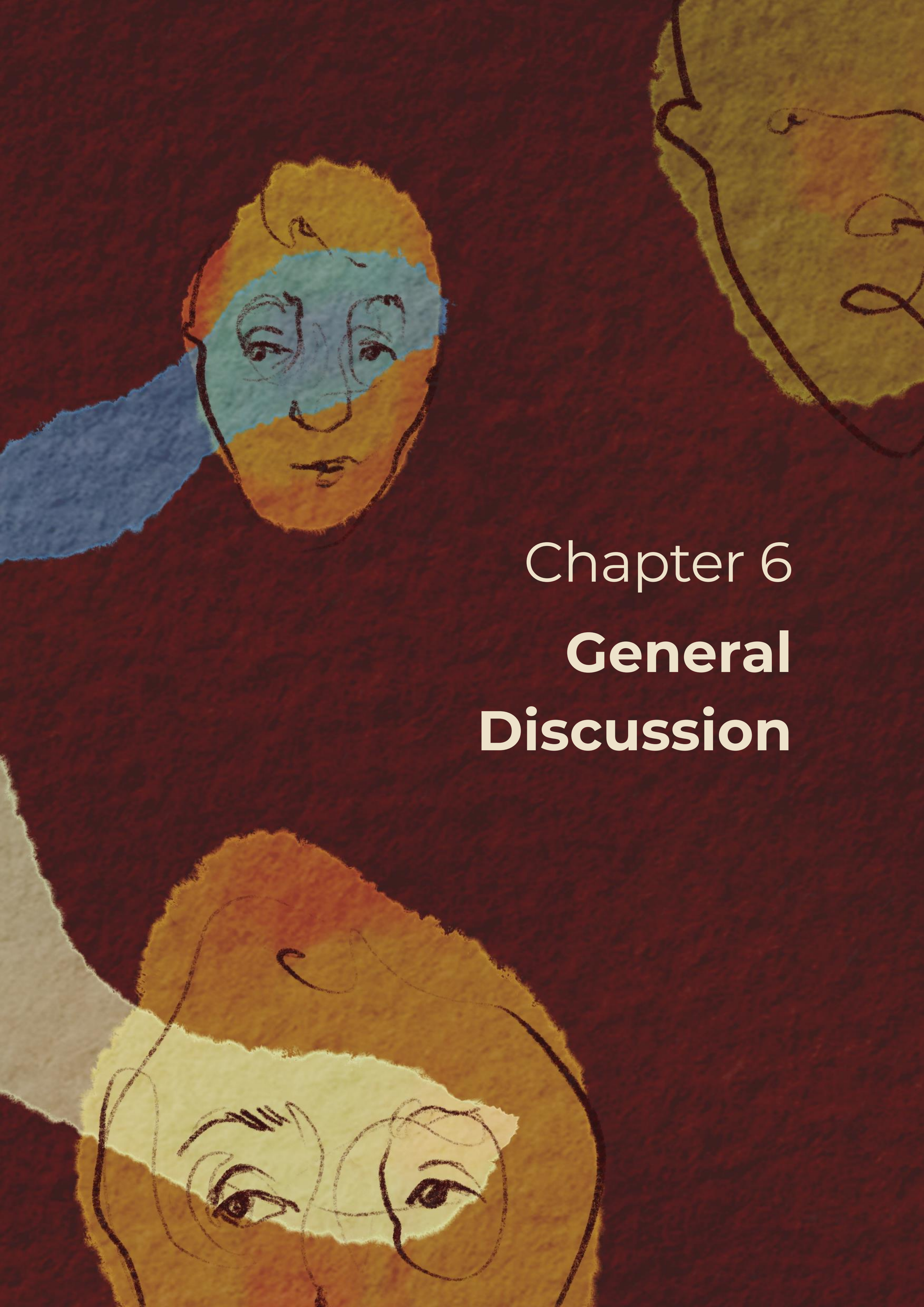
(Mosconi et al., 2005; Pelphrey et al., 2003, 2005), reaches its maximum cortical thickness between 5 and 11 years of age (Sowell et al., 2004) and, during this period, it also increases activity (Carter & Pelphrey, 2006).

It should be noted that our study is cross-sectional and, therefore, the developmental trajectory cannot be properly traced. Moreover, although 4-year-old data has been replicated in two experiments with different stimuli presentation, 6-year-old groups have shown mixed results. Understanding the developmental course of the attentional effects of gaze, especially between 4 and 12 years of age, will require additional studies. Another limitation of the present study was the difference in the sample size of Experiment 2. Although we have attempted to solve the potential methodological concerns by using an additional bootstrapping analysis, replicating the data with equivalent samples both in the number of participants and age would be desirable.

On the other hand, obtaining other socio-cognitive measures, such as Theory of Mind skills, would provide insight into potential moderators of the RCE. Further investigation is needed to test how social experience affects the observed developmental differences between gaze and arrows. For instance, by manipulating the identity of faces, i.e., adding the faces of parents or teachers, we would be able to assess whether, even in the youngest children, the greater social experience would influence the effect of gaze. In this sense, the next step could be to evaluate the RCE development in populations with atypical socio-cognitive skills, such as children and adolescents with ASD. It is important to highlight that our procedure is a simple experimental task where no verbal response is required, making it suitable for assessing both typically and atypically developing children.

Conclusion

The present study suggests that children develop specific attentional mechanisms to respond differently to gaze than to other nonsocial directional stimuli, such as arrows. Importantly, gaze and arrows seem to produce common attentional effects up to the early age of 4, but with social experience and perhaps brain maturation, gaze might gain additional qualities which affect its processing. Gaze direction becomes a valuable cue about other's focus of interest that besides orienting attention towards a direction, as arrows would do, can direct attention to a particular object or event, triggering its selection automatically. This particular attentional property of gaze, however, would only emerge later in childhood or adolescence.



Chapter 6

General Discussion

Is gaze a unique attentional stimulus? A view from different perspectives

"En los ojos se abren
infinitos senderos [...].
Las pupilas no tienen horizontes.
Nos perdemos en ellas
como en la selva virgen"

Federico García Lorca

Across the previous chapters, we have emphasized the importance of gaze in human development. Starting with an early preference for faces and direct gaze exhibited at birth (Farroni et al., 2002; Johnson et al., 1991), social experience and brain maturation enable an exponential growth of socio-communicative abilities throughout infancy, using gaze direction as an increasingly sophisticated attentional cue. During the first year of life, infants demonstrate a growing understanding of the referential function of gaze, enabling the coordination of attention with social partners to establish joint attention (Mundy, 2018). These early skills are critical milestones in learning and language development, as infants use gaze direction to map labels onto objects and learn about their properties, as well as to develop mentalistic processes such as the theory of mind (Brooks & Meltzoff, 2015; Delgado et al., 2002). Gaze-following behaviors also have diagnostic and prognostic implications for atypical socio-cognitive development, such as children with autism spectrum disorders (ASD) who manifest differences in the spontaneous and efficient use of gaze as a social cue (Mundy & Bullen, 2022).

Despite the undeniable social uniqueness of gaze as an attentional cue, recent research suggests that, at least with some experimental procedures, it does not orient attention any differently than other directional symbolic stimuli that lack social nature, such as arrows (Chacón-Candia, Román-Caballero, et al., 2023). However, once attention has been shifted to the indicated location, how attention interacts with objects may be distinct when guided by gaze. Specifically, whereas arrows usually produce a spread of attention in the indicated direction, gaze bias attention towards what is perceived as the attended object (Chacón-Candia et al., 2020; Chacón-Candia, Lupiáñez, et al., 2023; Marotta et al., 2012). This distinct selection may facilitate the encoding of gazed targets in memory (Dodd et al., 2012; Gregory & Jackson, 2017) and also influence their affective judgment (Bayliss et al., 2006).

To better understand these differences, it is crucial to employ paradigms that can effectively measure effects beyond the scope of attentional orientation. One approach that has successfully captured this dissociation is a spatial interference task, where the direction of gaze and arrows becomes the target itself. In this task, participants are instructed to make speeded responses to identify the direction, right or left, of lateralized arrows or eye gaze targets, while disregarding their spatial location. Arrows typically lead to a faster direction identification when it matches the irrelevant location (congruent conditions) than when they do not match, which is known as the spatial congruency effect (Kornblum et al., 1990b; Lu & Proctor, 1995). In contrast, gaze elicits the opposite pattern; a reversed congruency effect (RCE). In incongruent conditions, where there is a location-direction mismatch, direction identification is actually faster than in congruent conditions. This distinct effect of gaze has been widely replicated (Edwards & Bayliss, 2019; Hemmerich et al., 2022; Ishikawa et al., 2022; Jones, 2015; Marotta et al., 2018, 2019; Narganes-Pineda et al., 2022; Tanaka et al., 2022; Torres-Marín et al., 2017) and, over the past decade, researchers have been trying to uncover the mechanism behind this surprising opposite effect.

Summary of findings

This thesis attempted to gain insight into the attentional qualities of gaze using the spatial interference task as a tool to apprehend gaze-specific qualities. Our premise is that the RCE reflects the contribution of additional high-level social factors to the processing of gaze direction. Both behavioral (Hemmerich et al., 2022; Román-Caballero et al., 2021b) and neuroimaging evidence (Marotta et al., 2019, Narganes-Pineda, et al. 2023) support the idea of a common set of basic mechanisms operating at early processing stages, along with additional specific social factors probable included at later processing stages. When arrows or gaze are presented, they trigger an initial processing stage that involves encoding their location and direction. These two opposing forces, shared by all direction stimuli regardless of their social or nonsocial nature, contribute to the location-direction interference manifested by the congruency effect: facilitation of direction identification when there is no interference with the irrelevant attribute (i.e., the spatial location). Additionally, gaze incorporates specific mechanisms related to its unique ability to infuse intentionality, which we refer to as the "looking factor"

This thesis was built upon three key pillars. The **first** one aimed to uncover the **mechanism underlying the looking factor**, focusing on the recently proposed hypothesis of *joint distraction* (Hemmerich et al., 2022). This term refers to an automatic drive to search for and select the potentially attended object. *Distraction* occurs when gaze *jointly* directs attention outwards under congruent conditions. As a result, there would be a delay in responses which ultimately generates the RCE. In Chapter 3, we investigate whether the joint distraction hypothesis could explain the occurrence of the RCE by trying to override it. We modified the task by placing different items on the two potentially looked-at locations. As long as the gaze looks at those items, the attentional act would be fulfilled, which would equate orienting by arrows and gaze and prevent any gaze-induced distraction. In Study I, we introduced a surrounding bicolor frame in which one color was consistently presented at each end. We also included a group where participants not only observed the colors but also had to identify them. Despite these modifications, we replicated the standard and the reversed effect of arrow and gaze, respectively.

However, it could be argued that colors alone may not be sufficient to prevent distraction. In typical social interactions, the focus of someone's interest is usually an object, an action, or another person, rather than a color itself. Furthermore, since the colors were fixed (green on the right and red on the left), participants may have automatized their response by focusing on direction and ignoring colors.

To address these unresolved questions, we conducted Study II. Throughout this experimental series, we conducted various manipulations. Firstly, the presence or absence of objects did not affect the reversed effect of gaze, whether manipulated within blocks (Exp 1) or in separate blocks (Exp 2). The type of item used, whether objects (Exp 1, 2, and 4) or colors (Exp 3), did not have any effect, even when participants were required to actively process and respond to them (Exp 3 and 4). These findings suggest that the perception and identification of objects do not prevent joint distraction, highlighting the need to reevaluate the current theoretical framework. A further in-depth discussion about joint distraction can be found in the following sections.

The **second** pillar of this thesis focused on **individual differences**. In Study III (Chapter 4), we aimed to investigate whether individual differences in socio-cognitive processes, such as the presence or absence of autistic traits, in interaction with crucial components of social interaction, such as the facial emotional expression, modulate the gaze effect. Our findings revealed an emotional modulation of the RCE, which increased in response to faces expressing happiness compared to other emotions or neutral expressions. Importantly, individuals with high levels of autistic traits did not show this emotional modulation, further supporting the idea that a social mechanism underlies the RCE. However, since both individuals with low and high autistic traits exhibited the RCE, we decided to adopt a developmental approach to gain a better understanding of the course of this effect in typical development.

The **third** and final component of this thesis (Chapter 5) explored the **developmental trajectory** of differences between arrow and gaze, spanning from childhood to adolescence. We observed a gaze-specific effect that follows a prolonged developmental course during childhood. Specifically, the RCE was not present in 4-year-old children but progressively emerges throughout childhood until it reaches its adult form at 12 years of age. The fact that the gaze's RCE follows a distinct developmental sequence compared to arrows provides support for two main ideas. On the one hand, whatever the mechanisms behind RCE, they are gaze-specific, can be dissociated from those of the arrows, and exhibit a relatively late developmental onset. On the other hand, the basic and common processes of spatial and directional coding, which create spatial interference, are already present from the age of 4 and remain consistent over time, as evidenced by the unchanged response to arrows.

The "looking factor" seems to undergo a progressive development, ultimately leading to the reversal of the effect at age 12. During the period from 5 to 10 years, children may experience ongoing changes that result in inconsistent group patterns, possibly due to individual differences. For instance, 5-year-olds showed no congruency effect in response to gaze (Exp 1 from Study IV), while in a different experiment (Exp 3 from Study IV), 6-year-olds exhibited a standard effect. Notably, the reversion began to emerge at age 10 and reached statistical significance by the age of 12. This effect was also replicated in older adolescents aged 17 (Exp 3 from Study IV). A progressive development of this "looking factor" seems reasonable, as it needs to be strong enough to counteract the location-direction interference.

To recapitulate, the conclusions arising from the general pattern of results can be summarized as follows:

1. The joint distraction hypothesis, as currently formulated, is not confirmed. The presence of objects does not prevent the presumed distraction caused by the outward gaze, even when ensuring that participants attended to objects when a response is required.
2. Social components, such as emotional expression, play a role in modulating the congruency effect. The RCE increased when responding to happy faces compared to faces with neutral or other emotional expressions, suggesting that social factors could influence the effect.
3. Individual differences in socio-cognitive traits, specifically the level of autistic traits, interact with the emotional modulation of the effect.

Individuals with high levels of autistic traits do not show any emotional modulation, further supporting the role of social factors.

4. The developmental trajectory of the congruency effect differs between gaze and arrow targets. While the standard effect is already present at 4 years of age, the specific mechanisms underlying the RCE gradually develop during childhood and become strong enough to produce adult-like RCE in early adolescence.
5. The developmental data challenge the joint attention hypothesis, which proposed a benefit of jointly attending to the fixation cross when gaze looks inwards in incongruent trials, as 4-year-olds, who should already have a broad repertoire of joint attention skills, did not show the RCE for gaze. The late emergence of the RCE suggests the involvement of additional factors.

Building upon these conclusions, it becomes clear that a deeper reflection on the underlying mechanism of the specific effect of the gaze is necessary. While neither the joint attention nor joint distraction hypotheses have been confirmed, our findings support the notion that processing gaze direction involves two distinct processes. Firstly, there are initial processes common to directional stimuli that contribute to the standard spatial interference and are present from childhood. Secondly, additional specific effects are contributing to the RCE that emerges in early adolescence. Furthermore, our data indicate that the RCE is influenced by social factors, as its magnitude is modulated by emotions, which is absent in individuals with high levels of autistic traits. A more comprehensive discussion of the social foundation is developed in the section below titled "The social looking factor: an ongoing debate".

However, an alternative nonsocial explanation could also be considered as suggested by some authors (Chen et al., 2022). Arrows and gaze have perceptual dissimilarities, which may lead to the recruitment of different processes when selecting the direction. In the following sections, we will discuss both the social and nonsocial perspectives, examining how the data obtained in this thesis align with these two approaches, with the primary aim of shedding light on the possible origin of the differences between gaze and arrows.

A nonsocial account for the RCE: the perceptibility of targets

Several factors can impact the perceptibility of stimuli including salience, presentation duration, or the size of the task-relevant region. Usually, longer reaction times or lower accuracy rates indicate increased perceptual difficulty. As argued in previous studies (Chacón-Candia, Román-Caballero, et al., 2023; Hietanen et al., 2006; Vlamings et al., 2005), gaze would require a longer processing time compared to arrows due to its social burden and perceptual complexity.

It should be noticed that some authors have found the opposite pattern when using tasks based on the cueing paradigm: an overall longer response time for arrows than for gaze cues (Dalmaso et al., 2020b; Quadflieg et al., 2004). At first glance, it might seem reasonable for gaze to yield a quick orienting response. The biological and social relevance of eyes could trigger an attentional boost. The heterogeneity of experimental designs poses challenges in determining a definitive answer regarding differences in overall reaction time. Recent meta-analytic findings have identified moderating variables, including the presence or absence of a direct gaze before the averted one, which may help explain some of the observed variability (Mckay et al., 2021)

Nevertheless, the characteristic of the task can play a role in these different results. The spatial interference task differs from the cueing paradigm in some key aspects. When using gaze and arrows as cues, as in classic or similar-to-classic cueing paradigms, the resulting RT indicate their shared orienting property. In contrast, in the spatial interference task, the direction becomes the target, so that RTs could reflect a different mechanism. The RCE may be the result of both initial orienting mechanisms and posterior higher-level processes (Hemmerich et al., 2022; Marotta et al., 2019). Therefore, longer overall RTs would be expected for gaze targets than for arrows. In all studies, we repeatedly found this pattern of longer RT responding to gaze than to arrows, either when using cropped eyes (Study I and II) or faces (Study IV) and regardless of age, as adults (Study I and II) and all age groups from 4 to 17 years old (Study IV) showed this overall difference. Moreover, this is consistent with other studies using the same interference task (Z. Chen et al., 2022; Hemmerich et al., 2022; Marotta et al., 2018, 2019; Narganes-Pineda et al., 2022).

Apart from whether social relevance is linked to the increased processing time of gaze, a perceptual explanation has been proposed. As discussed in recent papers, the pupil embedded in the eyelid may be less salient than the arrowhead, requiring participants to adopt a small attentional zoom to encode gaze direction (Chen et al., 2022). A narrower attentional focus increases the likelihood of excluding task-irrelevant information, such as the location (Eriksen & James, 1986). The literature on well-known conflict effects, such as Stroop or Simon effects, has also shown a relationship between perceptibility and resulting interference (see Lu and Proctor, 1995 for a review). Specifically, Hommel (1993) interpreted these findings in terms of the temporal distance between the processing of relevant and irrelevant dimensions. When a stimulus appears, it rapidly and automatically activates a spatial code of its location that decays over time. If the relevant attribute of the stimulus, to which a response is required, is identified while the location code is still active, interference occurs. However, if there is a delay in identifying the relevant dimension, the interference is reduced or eliminated. This prediction has been tested by manipulating the perceptibility of the signal through its quality or the signal-background contrast. In both cases, increasing perceptual complexity reduces interference (Hommel, 1993).

Considering the greater perceptual complexity involved in processing eyes, this phenomenon could explain the observed differences between the congruency effect of gaze and arrow targets. The process of identifying gaze direction involves the selection of the pupil within the eyes, which can be further complicated when the eyes are part of a face. As a result, the selection of direction from the eyes may take longer compared to arrows. This temporal delay may effectively eliminate the conflict caused by location, thereby contributing to the observed reversed effect.

The perceptual hypothesis offers a possible explanation for the increased reversed congruency effect (RCE) observed when using faces as stimuli compared to cropped eyes, as faces provide a more complex visual background (see Cañadas & Lupiáñez, 2012 and Hemmerich et al., 2022, for experiments using the two stimuli and Román-Caballero et al., 2021a, for a comparison of the effect of faces and eyes). As mentioned in the introduction, this idea has also been applied to the spatial interference task, aiming to equalize the perceptual complexity of arrows and faces. When arrows were presented in an intricate background, the spatial interference was reduced or eliminated (Román-Caballero et al., 2021a, 2021b).

In this regard, other studies have attempted to perceptually match gaze and arrows by simplifying the eyes. In a recent study, Chen et al. (2022) compared two eyes extracted from a real picture (the same stimuli as in Study I and II, and Marotta et al., 2018) with two simplistic cartoon eyes, composed of a white oval and a black sphere resembling the pupil. The selection of direction was potentially easier in this latter simple background, making them perceptually comparable to arrows. In two separate experiments, the authors found an RCE responding to eyes (Experiment 1) and a standard effect responding to cartoon eyes (Experiment 3). In addition, the authors of the study attempted to create a symbol that was perceptually comparable to eyes but lacked their social nature. The symbol was an infinite form, conformed by two halves. One half was black, resembling the direction indicated by the pupil, and the other half was gray. It was presented within a rectangle that matched the color of the eyelids of real eyes. The results showed a similar reversed effect between the eyes and the symbol. However, it should be noticed that equalizing stimuli in perceptibility could be difficult, and, in fact, participants took longer to respond to the symbols compared to the eyes. Moreover, in the attempt to equalize low-level features, nonsocial symbols could end up resembling eyes, especially considering people's tendency for illusory perceive faces and eyes (i.e., pareidolia; Caruana & Seymour, 2022). Nevertheless, it is undeniable that perceptual factors seem to be involved in the observed effects, making it important to consider them (Chen et al., 2022).

Following this line of reasoning, it seems tempting to explain the emotional modulation of the effect, observed in both Study III and previous studies (Jones, 2015; Torres-Marín et al., 2017), in terms of the complexity involved in extracting direction from emotional faces. In all these studies, it was consistently found that the RCE was enhanced when responding to happy faces. Additionally, both Jones (2015) and Torres-Marín et al. (2017) reported a similar modulation in response to angry faces, while the latter study also found it for sad faces. Facial expressions involving wrinkles or muscle contractions around the eyes may introduce complexity in the selection of the signal, i.e., the pupil, from the background, thus influencing the strength of the RCE (Román-Caballero et al., 2021a)

However, perceptual difficulties do not explain all available data, and many of the arguments can also be nuanced from a social perspective.

Understanding the interplay between perceptual and social processes

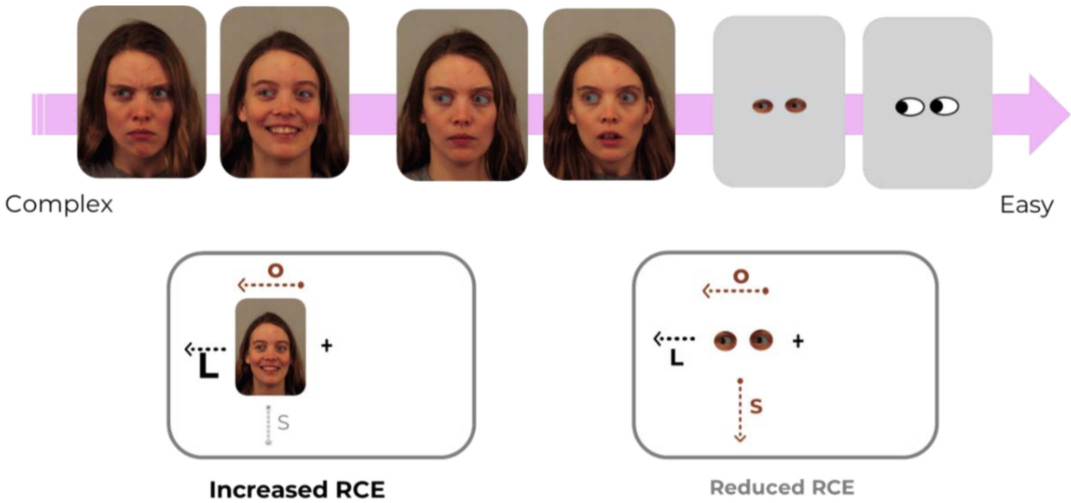
Just the difficulty in extracting direction does not fully explain the results observed with emotions such as fear. A fearful facial expression involves widely open eyes, making the pupil much easier to perceive (Walen et al., 2004), even more than a neutral expression. Accordingly, in Study III, both groups showed a faster and more accurate identification of direction in fearful faces. However, the resulting RCE seems comparable to that observed in neutral ones (Study III, and Jones, 2015). Far from being solely caused by perceptual reasons, the emotional modulation of faces appears to depend on the context. Following gaze cues, the facilitation in target detection (i.e., the gaze-cueing effect) is not solely modulated by the emotional expression of the face. Instead, it is influenced by the combination of emotion and the object being gazed at, showing an enhanced effect when a happy face looked at a positive stimulus (Bayliss et al., 2010). Therefore, the attentional system seems to integrate the facial emotional expression with their presumed intentionality (i.e., if a person is looking happily at an object, it must be because the object is pleasant).

A social-based explanation could also account for the absence of RCE in cartoon-like eyes, as they lack intentionality (Chen et al., 2022). The fact that gaze-cueing effects are observed for real and schematic eyes does not necessarily imply that similar results should be expected with the spatial interference task, as the intentionality of gaze might be better captured by this latter experimental procedure. Similarly, in the study conducted by Ishikawa et al. (2022) where robot and fish targets did not elicit the RCE, the absence of social communication due to not having communicative experiences with fish or the association of robots with a lack of intentionality may reduce the social effects of gaze. However, they also did not find the standard effect for these *nonsocial* stimuli. Moreover, the fish faces used in the experiment were artificially created, featuring pufferfish bodies that were inflated and covered in spikes, along with two small front-facing eyes. Although these pufferfish faces may entail complex signal-ground segregation, leading to reduced spatial interference and increased RCE, they did not exhibit produce the reversion. Hence, it appears that additional factors are necessary for the reversion to occur.

In short, perceptual factors can influence the observed RCE, but they seem not to be the sole determinants. The effect is likely shaped by a complex interplay between perceptual and social factors. Perceptual factors can modulate the strength of the common location-direction interference, either reducing or increasing it. Considering that the outcome of gaze is affected by both common and singular factors, reducing the interference would enhance the detection of this "looking factor", which may operate in the opposite direction. As represented in Figure 5, when signal selection becomes challenging, the spatial influence weakens, resulting in reduced interference and, hence, an increased RCE. Furthermore, social factors can enhance or diminish the influence of the looking factor. For instance, the stronger "looking factor" when presenting faces instead of cropped eyes may contribute to the larger RCE, as the presence of the entire face not only adds complexity to the extraction of direction but also enriches the perception of social information (Hadders-Algra, 2022).

Figure 5

Process Interplay Across Varying Levels of Complexity in the Selection of Gaze Direction

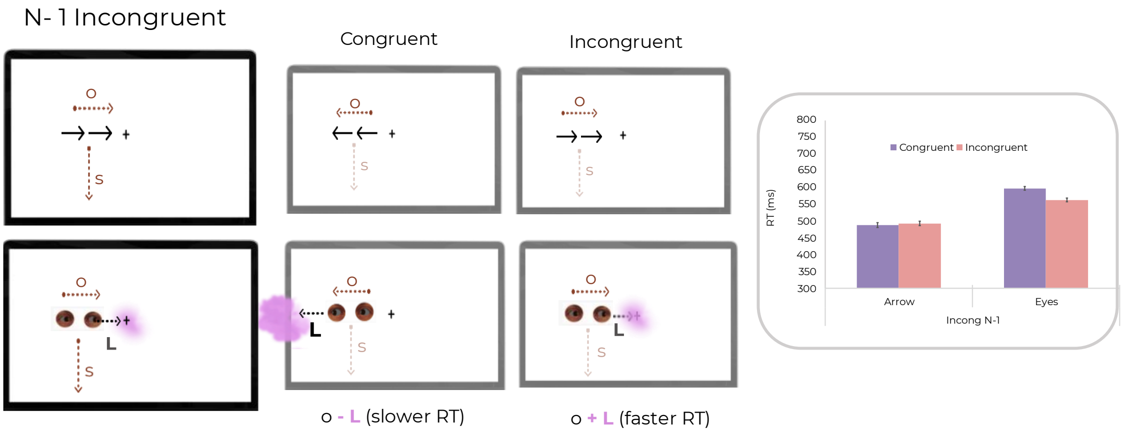


Note. In the top section, gaze stimuli are depicted in increasing complexity of gaze direction selection based on the background. This particular order is just a proposal based on the above-described data. In the bottom section, two incongruent trials are represented. On the left, the gaze direction would require more to be selected from the face, resulting in a decay of the spatial strength (s). In turn, the looking force is large, as faces provide rich social information. On the right, the cropped eyes enable quicker selection, thus spatial activation (s) exerting larger interference. In contrast, the looking force is reduced by the impoverished perception of social information with cropped eyes.

The results of sequential conflict effects (Hemmerich et al, 2002 and Study I and II) can be explained similarly, as the spatial interference is reduced by prior incongruency (see Figure 6). In incongruent conditions, the activation of the irrelevant location of targets ("s") interferes with direction ("o"), so that, to accurately select direction, we need to exert control to ignore location. In the next trial, the attentional system is prepared to handle interference by weakening the strength of the spatial activation that affects both arrows and gaze. However, the resulting outcome differs between the two targets as the reduction of interference does not impact the gaze's looking vector which operates in the opposite direction. As a result, we found an increased RCE.

Figure 6

Representation of the Presumed Factors Involved in Sequential Conflict Effects.



Note. The trials on the left represent the previous (N-1) incongruent or congruent, followed by the interplay that could occur in the subsequent trial based on congruency. The graph on the left represents the sequential effects found in Experiment 1 of Study II (no-object condition).

In summary, to understand the attentional effects caused by gaze, it is necessary to take into account both perceptual and social processes. While the above-described evidence suggests that perceptual differences may play a significant role in the final effect produced by gaze, the contributions of social components cannot be entirely ruled out. As mentioned in Chapter 1, eyes and arrows are inherently different stimuli, and our main focus of interest - the social contribution of eyes in the attentional processes - is likely closely related to their specific perceptual features. The shape, size, color, or expressiveness of eyes can all contribute to how they are processed in social interactions, and these features are not shared by arrows. The use of cropped eyes attempted to match the perceptual characteristics of arrows to derive a purely social explanation for any observed differences in attentional processing. Despite our efforts to match them, achieving a total perceptual equalization between the two stimuli may not be possible or even desirable, as the appreciation of social information largely improves when information about the entire face is available (Hadders-Lagra et al. 2022). Since these are two inherently distinct stimuli, it is unfeasible to ensure whether the observed differences stem from perceptual factors or if they genuinely involve different mechanisms.

The most effective way to overcome this challenge is to examine how the effects of these stimuli interact with individual social differences. This approach allows us to consider the influence of relevant social constructs, shedding light on the underlying mechanisms that are at play.

The social “looking factor”: An ongoing debate

The presence of a double dissociation, as observed in the modulation of distinct congruency effects of arrows and gaze by specific social components (such as emotions) and personality traits (such as the level of autistic traits), along with a different developmental trajectory, seems to indicate the influence of social factors. These findings challenge a purely perceptual explanation, as the stimuli remained constant while only individual characteristics varied.

Notably, individuals with high levels of autistic traits did not exhibit an emotional modulation of the RCE, yet their overall performance was comparable to the low-level group in both the interference task and the identification of emotional expressions. Perhaps, the specific challenge lies in integrating gaze direction with other social components. Extracting relevant information from the eyes is crucial for understanding emotions in combination with mental states (Itier & Batty, 2009). However, individuals with ASD often show difficulties integrating eye signals with both emotions (Akechi et al., 2009) and mental states (Baron-cohen & Wheelwright, 2010). Regardless of whether or not individuals with ASD struggle to recognize emotional expressions (see for example Ozonoff et al., 1990, for results of an analogous ability for labeling emotions when typical developing and autistic children were matched in verbal IQ), emotions may not be as salient as in people with typical development. For instance, children with ASD tend to describe faces based on accessories (i.e., hats), while neurotypical peers spontaneously categorize them based on facial expressions (Weeks & Hobson, 1987).

Besides the absence of an emotional modulation, the presence of an RCE in individuals with high levels of autistic traits is an interesting finding, especially since the RCE could be capturing a gaze-specific social factor that seems to have a late onset in typically developing children. The first and most important factor to consider is that our sample involves a subclinical population. The autistic spectrum encompasses not only categorical classifications but also a dimensional distribution within the general population. A high AQ score may denote a phenotype qualitatively similar to diagnosed individuals (Wheelwright et al., 2010). Still, a formal diagnosis implies distinct levels of severity and specific criteria. Consequently, all hypotheses regarding ASD should be considered tentative.

It is possible that the RCE, despite being a social outcome, may not be altered in intermediate phenotypes as indicated by the AQ scores. In this regard, research conducted with 6-month-old infants at high or low risk for autism has revealed attentional disparities that differentiate diagnosed children from those with milder phenotypes. Infants who were later diagnosed with ASD exhibited diminished overall attention toward social scenes, particularly spending less time looking at the person's face. This pattern differentiated infants with ASD from those showing some ASD-related impairments but no formal diagnosis (Chawarska et al., 2013). It is worth noting that the RCE may rely on basic social skills that remain unimpaired in adults with ASD. To draw more conclusive findings about the presence of an RCE in people with ASD, further research is necessary.

The presence of an emotional modulation in individuals with low levels of autistic traits aligns with the evidence from ERPs suggesting that the RCE occurs in a later stage of processing (Marotta et al., 2019). Studies on the temporal dynamics of gaze processing suggest that there are distinct stages involved in the processing of gaze information. The initial stages primarily involve the detection of gaze direction. This process is fast and may occur automatically. Subsequently, the attribution of intentionality and mentalistic judgments are incorporated in later stages (Itier & Batty, 2009). The RCE may be associated with this posterior step of gaze processing, possibly linked to intentionality. Gaze direction is often interpreted based on a person's intentional states (Baron-Cohen, Wheelwright, et al., 1997). Humans have an innate tendency to instinctively look at the objects that they are referencing, desiring, or preparing to interact with. Consequently, we naturally learn to follow the gaze of others to find their object of interest. Therefore, it is intriguing that the RCE does not emerge until the age of 12, despite 4-year-olds already possessing a well-developed repertoire of joint attention skills.

While joint attention may play a role, additional mechanisms may contribute to the occurrence of the RCE. One potential explanation is that the act of looking away from the screen in the absence of a specific object to fixate upon, as in the congruent condition of the interference task, creates a sense of social dissonance. A similar social unease may account for the *inward bias* observed when perceiving paintings or photographs, where people prefer characters to look inward at the interior of the scene. In contrast, during congruent trials of the interference task, the eyes look outward in congruent trials of the interference task, which may create a (joint) distraction when searching for the potential object of interest. Consequently, this distraction may result in a slowdown in the identification of gaze direction, and, hence, the RCE.

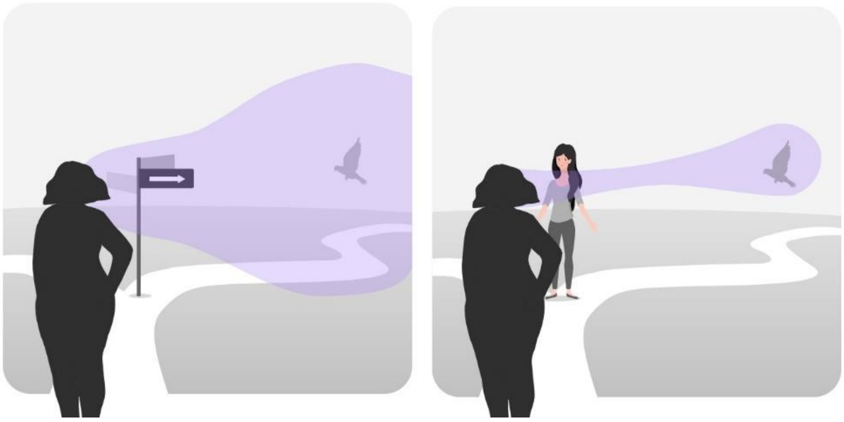
However, as explored in Chapter 2, the presence of lateralized objects does not appear to have a significant impact on the effect. Despite this presumed distraction would be overruled by the presence of objects, the RCE persisted, suggesting that other factors may be at play. Nevertheless, there are some alternative explanations for this outcome (see the discussion section of Study II). On the one hand, specific aspects of the task design, such as a pre-exposure to objects prior to the appearance of targets, might have influenced the RCE either by increasing spatial interference or by weakening the social effect (Román-Caballero et al., 2021a, 2021b). On the other hand, the RCE may be indeed related to a search for an object that would be attentionally selected, i.e., a joint distraction process, but the effects may only manifest at later stages of processing, beyond the initial perception or identification of objects. For instance, participants might be distracted by keeping attention on the object after attending to it despite being irrelevant to the task.

In other words, eyes may not only guide attention but also complete the selection process by indicating the exact object of interest. This distinction highlights the potential for eyes to have a greater impact on attentional selection compared to arrows. As exemplified in Figure 7, when we see a signpost signaling a direction, our attention is directed towards the general indicated area, towards the pathway. The allocation of attentional resources in this direction enables us to perceive the flying bird. In contrast, when we observe a person looking in that direction, our attention is not only shifted towards that direction but also automatically activates an additional mechanism ascribing intentionality, understanding that the person is looking at something. Consequently, the bird might be attentionally selected. This subtle difference could result in variations in how the bird is processed. It is possible that when another person has previously looked at the bird, we would remember it better (Dodd et al., 2012; Gregory & Jackson, 2017) or even find it more appealing (Bayliss et al., 2006).

This hypothesis aligns with the findings regarding the specificity of gaze-attentional orienting. Gaze direction restricted attention to the location being gazed at, in contrast to a broader and more unspecific attentional orienting when initiated by arrows (Chacón-Candia et al., 2020; Chacón-Candia, Lupiáñez, et al., 2023; Marotta et al., 2012). A similar specific selection may occur with gaze-induced Inhibition of Return (IoR), where the gaze, but not the arrow, automatically selects the object being gazed at, resulting in the cost of IoR (Frischen & Tipper, 2004).

Figure 7

Representation of two Distinct Attentional Mechanisms Following Arrows or Gaze



The emotional modulation observed in the RCE could be explained in the same vein. A fearful face with an averted gaze could trigger a rapid attentional shift toward potentially threatening stimuli (Putman et al., 2006). However, it is possible that unlike faces displaying happy expressions, the object selection following a fearful face may be reduced to facilitate escape or attending the next event. In fact, ERPs data on the processing of emotional faces show two distinct levels of processing depth depending on the participant's intention, for example, depending on whether they are passively observing faces or actively responding to them. During the early stages of processing (P1, N170, and early posterior negativity; EPN), an angry expression appeared to enhance processing regardless of intentionality, which was interpreted by the authors as an early perceptual threat bias. However, the encoding of happy expressions depended on the intention to process the stimuli more deeply (Rellecke et al., 2012).

Irrespective of the underlying mechanism, whether it is social or otherwise, our data from Study IV reveal distinct developmental changes between ages 4 and 12 specifically in response to gaze, but not arrow direction. This finding is consistent across two experiments involving different groups and stimuli manipulations. Although the existence of a joint distraction effect is speculative, changes observed within this particular age range could open new lines of exploration. Following the developmental trajectory of the first year of life introduced in Chapter 1, eye gaze grows in complexity as an attentional cue, progressing from signaling general directionality to detecting objects even outside of the visual field; inferring that the other person can see them. Social cognition abilities continue to develop over time as most of them are mutually dependent and interact with other cognitive functions. Therefore, it is difficult to categorize them as fully acquired as they continue to evolve and improve over time (Beaudoin & Beauchamp, 2020; Brizio et al., 2015). Similarly, a joint distraction effect could be the result of progressive refinement.

One possibility is that beyond the age of 4, the joint distraction mechanism becomes automatically integrated when processing gaze direction, regardless of the task at hand. Indeed, participants are not required to follow gaze direction in the spatial interference task but rather to identify it. Perhaps the ability to automatically decode agency from gaze in any context develops with experience, by consistently experiencing that "people look at something". At the age of 4, neurotypical children have developed a full set of gaze-processing skills, including the ability to infer mental states based on gaze direction. For instance, they understand that when someone's gaze is not directed at a particular object, it implies that they must be thinking (Baron-Cohen et al., 1997). This same association could generate over time an incidental distraction, whether in real-life situations or just watching eyes on a screen. Eyes looking away from the task, where no relevant information is present, may gradually increase a sense of social dissonance. Actually, children between the ages of 3 and 5 undergo a developmental shift in how they understand and use gaze direction. By the age of 5, but not at 3, children demonstrate the ability to follow gaze direction to find a hidden object, even when the verbal affirmation is contradictory. By this age, children recognize gaze as an uncontrollable communicative signal that conveys truthful information, regardless of attempts to hide it (Freire et al., 2004).

Adolescence is a period of multi-faceted changes, intertwining social experiences, hormonal changes, and brain maturation (Blakemore, 2008; Brizio et al., 2015), all of these coupled with improvements in abilities such as the theory of mind, which continues to develop between the ages of 11 and 15 (Beaudoin & Beauchamp, 2020; Bosco et al., 2014). Interestingly, another attentional effect that dissociates the effect of gaze and arrows, namely the gaze-induced IoR, has also been observed to emerge during early adolescence. Although the attentional system is primed to be automatically captured by abrupt peripheral stimuli by the age of 6, as children at this age showed IoR with such cues, the automaticity with central gaze cues emerges around the age of 9. Furthermore, this effect could be linked to other socio-cognitive factors, as young individuals with Asperger (between 10 and 18 years old) who show IoR with peripheral cues, do not show gaze-induced IoR (Marotta, et al., 2013).

Interestingly, around the same ages as the emergence of the RCE and the gaze-induce IoR, approximately at 10 years old, the ability to combine gaze direction and emotions also sharpens (Pecchinenda & Petrucci, 2021) this integration has been associated with a more nuanced capacity to infer the focus of interest of other people (Baron-cohen & Wheelwright, 2010). A specialization process has also been observed in ERPs data, with developmental changes in the N170 in response to eyes from 4 to 15 years of age, and reaching the adult pattern at around 11 years old (Taylor et al., 2001).

Some data about the developmental course of gaze-related areas in the brain, seem to fit with this period of changes. In particular, the superior temporal sulcus (STS) has been associated with extracted directional information for gaze and its activity seems to be sensitive to whether the gaze is directed at an object, with gaze looking at an empty space evoking a longer STS activation compared to gaze shift directed to targets. Therefore, it has been associated with goal-directed gaze shifts (Pelphrey et al., 2003). This differential activity has been also observed in neurotypical children between 7 and 10 years old (Mosconi et al., 2005), but not in adults with ASD (Pelphrey et al., 2005).

Inferring social meaning through our mentalistic skills is deeply ingrained in human behavior. The so-called *Heider-Simmel* effect serves as a clear illustration of this idea. In their classic experiment (Heider & Simmel, 1944), participants watched a video featuring simple geometric figures moving toward and away from each other. Subsequently, participants spontaneously described the scene ascribing purposeful intentions, emotions, and personalities to the geometric shapes. Despite the simplicity of the two-dimensional forms, people applied social interpretations to describe the action. Similarly, even in basic experimental settings, the mere presence of a face or a pair of eyes on a screen may trigger the entire social machinery. This incidental social activation may not be required for successful task performance, but it can still be detected through secondary measures that do not affect the main measured outcome. For example, participants may exhibit longer processing times for gaze compared to arrows, even when showing a similar cueing effect (Vlamings et al., 2005), or they may demonstrate an attentional bias towards looking at people's eyes during social scene viewing, regardless of the task at hand (Del Bianco et al., 2019).

In the case of individuals with ASD, this spontaneous social integration may not occur as readily, as we have observed in Study III with facial emotional expressions. Regarding the previous examples, individuals with ASD may exhibit the same cueing effect as typically developing individuals, but they do not show longer processing times for gaze compared to arrows (Vlamings et al., 2005). Moreover, individuals with ASD do not show a bias for looking at people's eyes, but they increase their frequency of looking at the face when explicitly required to provide a correct response to the task (Del Bianco et al., 2018). Furthermore, in experiments using the Heider and Simmel video, individuals with ASD identify fewer social elements and mentalistic actions, describing the scene by focusing on the movement itself. A reduced intentionality interpretation has also been observed using simpler clips where the action was a basic goal-directed movement (Bal et al., 2013; Rasmussen & Jiang, 2019).

In essence, understanding how the social dimension contributes to the attentional processing of gaze can be challenging. It is crucial to use sensitive paradigms that account for qualitative differences while also considering their interaction with individual differences and related social attributes. The results obtained so far contribute to and broaden existing hypotheses, but they also raise new questions. To deepen our understanding of the singular attentional processes of gaze, several promising lines can be explored.

Future lines of research

The discussion highlights the intricate interplay of attentional mechanisms involved in processing gaze direction. One approach to consider is investigating the influence of the common spatial conflict between gaze and arrows. Modifying the shared spatial conflict can have varied implications for the observed RCE. Insights from the literature on cognitive conflicts, such as the Stroop effect, can guide the manipulation of this interference by increasing or reducing it. For example, peripheral cueing, known to reduce Stroop interference (Funes et al., 2007), may lead to an amplified RCE. Similarly, the influence of perceptual factors can be further explored. Instead of simplifying eyes, which may compromise their social qualities, a more comprehensive approach involves making arrows more complex to align their perceptual burden with the eyes. However, it is important to strike a balance between arrow complexity and resemblance to faces or eyes, ensuring their distinct nature is maintained.

The joint distraction hypothesis opens up several avenues of investigation. Firstly, it is important to examine the potential impact of the joint distraction mechanism on the processing of gazed-at objects. The distraction caused by gaze could entail the allocation of attentional resources to the gazed object, enhancing processing beyond mere perception or detection. As demonstrated in the study by Gregory et al. (2017), gaze can influence the encoding of targeted objects in memory, resulting in a better subsequent recall compared to objects indicated by arrows.

Exploring the distinctions between the attentional orienting mechanisms of gaze and arrows also presents intriguing possibilities. One option is to use paradigms that have demonstrated a dissociation in orienting mechanisms, such as the adaptations of the two rectangles paradigm (Chacón-Candia et al., 2020; Marotta et al., 2012), in conjunction with other complementary measures, such as event-related potentials (ERPs). This approach could shed light on the potential differences in attentional selection produced by gaze compared to arrows, considering components such as the N2Pc associated with attentional capture (Eimer, 1996).

To further understand how developmental and socio-cognitive differences interact with attention to gaze and arrows, valuable insights can be gained from studying individuals with ASD. It would be particularly interesting to compare the developmental trajectory of children with typical and atypical development. Moreover, incorporating new sources of information, such as complementary behavioral observations, eye-tracking measures, and standardized assessments of socio-cognitive abilities, like the theory of mind, can enrich our theoretical knowledge and have potential clinical implications. In this sense, examining the modulation of the RCE by emotions in children represents another compelling avenue for future exploration.

Additionally, exploring the impact of facial identity on the RCE can yield intriguing findings. Factors like adjusting similarity between face targets and participants (e.g., age, gender) or manipulating face trustworthiness offer a range of possibilities for investigation. For instance, faces previously associated with deceptive responses may induce less distraction, resulting in a smaller RCE compared to trustworthy faces. In the case of children, familiar faces could enhance joint distraction due to their social learning history. Therefore, by using the faces of familiar adults, such as the face of their caregivers, we may observe an RCE even in 4-year-old children.

Concluding remarks

Whether based on the spatial interference paradigm or other cueing-like paradigms, a strict interpretation based on a domain-general account may not entirely explain the observed differences between eye gaze and arrows. The distinct modulations of information processing when gaze and arrows are used as cues, as well as the opposite spatial interference effects when they are used as targets, imply the contribution of different attentional processes. As directional stimuli, both may initiate a similar orienting process to select the indicated location. However, once attention is directed, gaze would activate additional and specific mechanisms probably linked to mentalizing functions. This "looking factor" may influence information processing by establishing an automated link between gaze and objects and ascribing intentionality. Perceiving a person looking outward without a specific attentional focus can evoke a sense of social dissonance, leading to an automatic (joint) distraction as we search for the potentially gaze-at object that would become attentionally selected.

In this complex interplay, perceiving and identifying objects may not be enough to counteract the joint distraction mechanism. Further investigation is warranted to examine the potential impact of a unique attentional selection induced by gaze on subsequent processing stages, such as memory encoding. Our findings suggest that social factors, particularly the emotional expression of the observed face, interact with the gaze's RCE. Specifically, happy faces may enhance the magnitude of the effect through an increased distraction towards a potentially positive looked-at object. It is worth noting that individual variations in socio-cognitive aspects seem to shape this modulation, as evidenced by the absence of emotional effects in individuals with higher levels of autistic traits. Furthermore, our data also indicate a distinct developmental trajectory in the attentional response to gaze compared to arrows. While common attentional mechanisms for both social and nonsocial stimuli seem to be present at the age of 4, unique gaze effects gradually refine and become automatic over time, reaching an adult-level RCE around 12 years old; a period with significant social, neural, and cognitive changes.

The hypotheses explaining the underlying mechanism of the reversed effect of gaze are promising but still speculative, highlighting the need for a theoretical deepening. Exploring the attentional particularities of gaze, by dissociating it from nonsocial stimuli, carries implications not only at a theoretical level, enriching the literature on social attention, but also has practical importance. Understanding how and when different social milestones are acquired is worthwhile, particularly considering the cascade of socio-cognitive processes that build upon gaze processing. Finding a gaze-specific attentional effect emerging in adolescence holds significant implications that call for further investigation and understanding. In practical terms, this raises intriguing questions, such as the potential impact of the digital environment on social development, given the growing exposure to social interactions through screens during this crucial developmental stage.

Furthermore, delving into the study of gaze will deepen our comprehension of the typical and atypical sequence of social attention development. Particularly in the case of autism spectrum disorders, the possibility to exploit an implicit index of social attention, dissociable from a general-domain measure, becomes a worthy endeavor. If future studies confirm the presence of social components underlying the RCE, this task could evolve into a valuable evaluation tool in educational and clinical contexts, offering a quick and easy implementation without requiring verbal responses. Ultimately, a deeper knowledge of gaze processing could benefit early interventions that maximize communicative opportunities through the gaze.

While many questions remain unanswered, we hope that this thesis constitutes a little step forward. The evidence in the coming years may unveil the intricate mechanisms of this critical aspect of human interaction.

References

REFERENCES

Adams, R. B., & Kleck, R. E. (2003). Perceived gaze direction and the processing of facial display of emotion. *Psychological Science*, *14*(6), 644–647. https://doi.org/10.1046/j.0956-7976.2003.psci_1479.x

Adams, R. B., & Kleck, R. E. (2005). Effects of direct and averted gaze on the perception of facially communicated emotion. *Emotion*, *5*(1), 3–11. https://doi.org/10.1037/1528-3542.5.1.3

Adamson, L. B., Bakeman, R., & Deckner, D. F. (2004). The Development of Symbol-Infused Joint Engagement. *Child Development*, *75*(4), 1171–1187. https://doi.org/10.18042/cepc/aijc.19.17

Akechi, H., Senju, A., Kikuchi, Y., Tojo, Y., Osanai, H., & Hasegawa, T. (2009). Does gaze direction modulate facial expression processing in children with autism spectrum disorder? *Child Development*, *80*(4), 1134–1146. https://doi.org/10.1111/j.1467-8624.2009.01321.x

American Psychiatric Association. (2013). Diagnostic and Statistical Manual of Mental Disorders. *Diagnostic and Statistical Manual of Mental Disorders*. https://doi.org/10.1176/APPI.BOOKS.9780890425596

Ando, S. (2004). Perception of Gaze Direction Based on Luminance Ratio. *Http://Dx.Doi.Org/10.1068/P5297*, *33*(10), 1173–1184. https://doi.org/10.1068/P5297

Apperly, I. A., & Butterfill, S. A. (2009). Do Humans Have Two Systems to Track Beliefs and Belief-Like States? *Psychological Review*, *116*(4), 953–970. https://doi.org/10.1037/a0016923

Aranda-Martín, B., Ángeles Ballesteros-Duperón, M., & Lupiáñez, J. (2023). Attentional differences between gaze and arrows processing: where vs. what are eyes looking at. *Psicologica*, *44*(2), 15274. https://doi.org/10.20350/digitalCSIC/15274

Aranda-Martín, B., Ballesteros-Duperón, M. Á., & Lupiáñez, J. (2022a). Dime dónde miras y te diré qué quieres : Efectos atencionales de la mirada en la adolescencia temprana. *Ciencia Cognitiva*, *18*(2), 25–28.

Aranda-Martín, B., Ballesteros-Duperón, M. Á., & Lupiáñez, J. (2022b). What gaze adds to arrows: Changes in attentional response to gaze versus arrows in childhood and adolescence. *British Journal of Psychology*, *113*(3), 718–738. https://doi.org/10.1111/BJOP.12552

Bal, E., Yerys, B. E., Sokoloff, J. L., Celano, M. J., Kenworthy, L., Giedd, J. N., & Wallace, G. L. (2013). Do social attribution skills improve with age in children with high functioning autism spectrum disorders? *Research in Autism Spectrum Disorders*, *7*(1), 9–16. https://doi.org/10.1016/j.rasd.2012.07.004

Bar-Haim, Y., Ziv, T., Lamy, D., & Hodes, R. M. (2006). Nature and nurture in own-race face processing. *Psychological Science*, *17*(2), 159–163. https://doi.org/10.1111/J.1467-9280.2006.01679.X

Baron-cohen, S. (2001). Theory of mind in normal development and autism. *Prisme*, *34*, 174–183.

Baron-cohen, S. (2005). The Empathizing System: a revision of the 1994 model of the Mindreading System. In D. Ellis, B, & Bjorklund (Ed.), *Origins ofthe social mind: Evolutionary psychology and child development* (Guilford P, Issue January 2005, pp. 468–492). Guilford Publications Inc.

Baron-Cohen, S., Baldwin, D. A., & Crowson, M. (1997). Do Children with Autism Use the Speaker's Direction of Gaze Strategy to Crack the Code of Language? *Child Development*, *68*(1), 48. https://doi.org/10.2307/1131924

Baron-Cohen, S., Campbell, R., Karmiloff-Smith, A., Grant, J., & Walker, J. (1995). Are children with autism blind to the mentalistic significance of the eyes? *British Journal of Developmental Psychology*, *13*(4), 379–398. https://doi.org/10.1111/J.2044-835X.1995.TB00687.X

Baron-cohen, S., & Wheelwright, S. (2010). *Is There a " Language of the Eyes "?*

Evidence from Normal Adults , and Adults with Autism or Asperger Syndrome. *December 2014*, 37–41. https://doi.org/10.1080/713756761

Baron-Cohen, S., Wheelwright, S., & Jolliffe, T. (1997). Is there a “language of the eyes”? Evidence from normal adults, and adults with autism or Asperger Syndrome. *Visual Cognition*, *4*(3), 311–331. https://doi.org/10.1080/713756761

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-Spectrum Quotient (AQ): Evidence from Asperger Syndrome/High-Functioning Autism, Males and Females, Scientists and Mathematicians. *Journal of Autism and Developmental Disorders*, *31*(1), 5–17. https://doi.org/10.1023/A:1005653411471

Batki, A., Baron-Cohen, S., Wheelwright, S., Connellan, J., & Ahluwalia, J. (2000). Is there an innate gaze module? Evidence from human neonates. *Infant Behavior and Development*, *23*(2), 223–229. https://doi.org/10.1016/S0163-6383(01)00037-6

Bayliss, A. P., Di Pellegrino, G., & Tipper, S. P. (2004). Orienting of attention via observed eye gaze is head-centred. *Cognition*, *94*(1), B1–B10. https://doi.org/10.1016/j.cognition.2004.05.002

Bayliss, A. P., Paul, M. A., Cannon, P. R., & Tipper, S. P. (2006). Gaze cuing and affective judgments of objects: I like what you look at. In *Psychonomic Bulletin and Review* (Vol. 13, Issue 6, pp. 1061–1066). Springer New York LLC. https://doi.org/10.3758/BF03213926

Bayliss, A. P., Pellegrino, G. Di, & Tipper, S. P. (2005). Sex differences in eye gaze and symbolic cueing of attention. *Https://Doi.Org/10.1080/02724980443000124*, *58*(4), 631–650. https://doi.org/10.1080/02724980443000124

Bayliss, A. P., Schuch, S., & Tipper, S. P. (2010). Gaze cueing elicited by emotional faces is influenced by affective context. *Visual Cognition*, *18*(8), 1214–1232. https://doi.org/10.1080/13506285.2010.484657

Bayliss, A. P., & Tipper, S. P. (2005). Gaze and arrow cueing of attention reveals individual differences along the autism spectrum as a function of target context. *British Journal of Psychology*, *96*(1), 95–114. https://doi.org/10.1348/000712604X15626

Beaudoin, C., & Beauchamp, M. H. (2020). Social cognition. In *Handbook of Clinical Neurology* (Vol. 173, pp. 255–264). Elsevier B.V. https://doi.org/10.1016/B978-0-444-64150-2.00022-8

Bellagamba, F., Addessi, E., Focaroli, V., Pecora, G., Maggiorelli, V., Pace, B., & Paglieri, F. (2015). False belief understanding and “cool” inhibitory control in 3-and 4-years-old Italian children. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.00872

Bernoster, I., De Groot, K., Wieser, M. J., Thurik, R., & Franken, I. H. A. (2019). Birds of a feather flock together: Evidence of prominent correlations within but not between self-report, behavioral, and electrophysiological measures of impulsivity. *Biological Psychology*, *145*, 112–123. https://doi.org/10.1016/j.biopsycho.2019.04.008

Bialystok, E., Craik, F., & Luk, G. (2008). Cognitive Control and Lexical Access in Younger and Older Bilinguals. *Journal of Experimental Psychology: Learning Memory and Cognition*, *34*(4), 859–873. https://doi.org/10.1037/0278-7393.34.4.859

Bigelow, A. E., & Power, M. (2016). Effect of Maternal Responsiveness on Young Infants’ Social Bidding-Like Behavior during the Still Face Task. *Infant and Child Development*, *25*(3), 256–276. https://doi.org/10.1002/ICD.1974

Bird, G., Catmur, C., Silani, G., Frith, C., & Frith, U. (2006). Attention does not modulate neural responses to social stimuli in autism spectrum disorders. *NeuroImage*, *31*(4), 1614–1624. https://doi.org/10.1016/J.NEUROIMAGE.2006.02.037

Blair, C. D., Capozzi, F., & Ristic, J. (2017). Where is your attention? Assessing individual instances of covert attentional orienting in response to gaze and arrow cues. *Vision (Switzerland)*, *1*(3), 1–13. https://doi.org/10.3390/vision1030019

Blakemore, S. J. (2008). The social brain in adolescence. In *Nature Reviews Neuroscience* (Vol. 9, Issue 4, pp. 267–277). https://doi.org/10.1038/nrn2353

Bosco, F. M., Gabbatore, I., & Tirassa, M. (2014). A broad assessment of theory of mind in adolescence: The complexity of mindreading. *Consciousness and Cognition*, *24*(1), 84–97. https://doi.org/10.1016/j.concog.2014.01.003

Braem, S., Abrahamse, E. L., Duthoo, W., Notebaert, W., & Gade, M. (2014). *What determines the specificity of conflict adaptation? A review, critical analysis, and proposed synthesis*. *5*. https://doi.org/10.3389/fpsyg.2014.01134

Brignani, D., Guzzon, D., Marzi, C. A. A., & Miniussi, C. (2009). Attentional orienting induced by arrows and eye-gaze compared with an endogenous cue. *Neuropsychologia*, *47*(2), 370–381. https://doi.org/10.1016/j.neuropsychologia.2008.09.011

Brizio, A., Gabbatore, I., Tirassa, M., & Bosco, F. M. (2015). "No more a child, not yet an adult": Studying social cognition in adolescence. *Frontiers in Psychology*, *6*(AUG), 1–12. https://doi.org/10.3389/fpsyg.2015.01011

Brooks, R., & Meltzoff, A. N. (2002). The importance of eyes: how infants interpret adult looking behavior. *Developmental Psychology*, *38*(6), 958–966. https://doi.org/10.1037//0012-1649.38.6.958

Brooks, R., & Meltzoff, A. N. (2005). The development of gaze following and its relation to language. In *Developmental Science* (Vol. 8, Issue 6, pp. 535–543). https://doi.org/10.1111/j.1467-7687.2005.00445.x

Brooks, R., & Meltzoff, A. N. (2015). Connecting the dots from infancy to childhood: A longitudinal study connecting gaze following, language, and explicit theory of mind. *Journal of Experimental Child Psychology*, *130*, 67–78. https://doi.org/10.1016/j.jecp.2014.09.010

Bruin de, A., & Sala, S. Della. (2018). Effects of age on inhibitory control are affected by task-specific features. *Quarterly Journal of Experimental Psychology*, *71*(5), 1219–1233. https://doi.org/10.1080/17470218.2017.1311352

Bruinsma, Y., Koegel, R. L., & Koegel, L. K. (2004). Joint attention and children with autism: A review of the literature. *Mental Retardation and Developmental Disabilities Research Reviews*, *10*(3), 169–175. https://doi.org/10.1002/mrdd.20036

Buiatti, M., Di Giorgio, E., Piazza, M., Polloni, C., Menna, G., Taddei, F., Baldo, E., & Vallortigara, G. (2019). Cortical route for facelike pattern processing in human newborns. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(10), 4625–4630. https://doi.org/10.1073/pnas.1812419116

Burra, N., Mares, I., & Senju, A. (2019). The influence of top-down modulation on the processing of direct gaze. In *Wiley Interdisciplinary Reviews: Cognitive Science* (Vol. 10, Issue 5). Wiley-Blackwell. https://doi.org/10.1002/wcs.1500

Butler, S. C., Caron, A. J., & Brooks, R. (2000). Infant Understanding of the Referential Nature of Looking. *Journal of Cognition and Development*, *1*(4), 359–377. https://doi.org/10.1207/S15327647JCD0104_01

Butterworth, G., & Jarrett, N. (1991). What minds have in common is space: Spatial mechanisms serving joint visual attention in infancy. *British Journal of Developmental Psychology*, *9*(1), 55–72. https://doi.org/10.1111/j.2044-835x.1991.tb00862.x

Cañadas, E., & Lupiáñez, J. (2012). Spatial interference between gaze direction and gaze location : A study on the eye contact effect. *The Quarterly Journal of Experimental Psychology*, *65:8*(8), 1586–1598. https://doi.org/10.1080/17470218.2012.659190

Capozzi, F., & Ristic, J. (2020). Attention AND mentalizing? Reframing a debate on social orienting of attention. *Visual Cognition*, *28*(2), 97–105. https://doi.org/10.1080/13506285.2020.1725206

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*, *28*(2), 595–616. https://doi.org/10.1207/s15326942dn2802_3

Carter, E. J., & Pelphrey, K. A. (2006). School-aged children exhibit domain-specific responses to biological motion. *Social Neuroscience*, *1*(3–4), 396–411. https://doi.org/10.1080/17470910601041382

Caruana, N., & Seymour, K. (2022). Objects that induce face pareidolia are prioritized by the visual system. *British Journal of Psychology*, *113*(2), 496–507. https://doi.org/10.1111/BJOP.12546

Çetinçelik, M., Rowland, C. F., & Snijders, T. M. (2021). Do the Eyes Have It? A Systematic Review on the Role of Eye Gaze in Infant Language Development. In *Frontiers in Psychology* (Vol. 11, p. 589096). Frontiers Media S.A. https://doi.org/10.3389/fpsyg.2020.589096

Chacón-Candia, J., Lupiáñez, J., Casagrande, M., & Marotta, A. (2020). Sex Differences in Attentional Selection Following Gaze and Arrow Cues. *Frontiers in Psychology*, *11*(February), 1–8. https://doi.org/10.3389/fpsyg.2020.00095

Chacón-Candia, J., Lupiáñez, J., Casagrande, M., & Marotta, A. (2023). Eye-Gaze direction triggers a more specific attentional orienting compared to arrows. *PloS One*, *18(1)*, 1–15. https://doi.org/10.1371/journal.pone.0280955

Chacón-Candia, J., Román-Caballero, R., Aranda-Martín, B., Casagrande, M., Lupiáñez, J., & Marotta, A. (2023). Are there quantitative differences between eye-gaze and arrow cues? A meta-analytic answer to the debate and a call for qualitative differences. *Neuroscience & Biobehavioral Reviews*, *144*. https://doi.org/10.1016/j.neubiorev.2022.104993

Charman, T., Baron-Cohen, S., Swettenham, J., Baird, G., Cox, A., & Drew, A. (2000). Testing joint attention, imitation, and play as infancy precursors to language and theory of mind. *Cognitive Development*, *15*(4), 481–498. https://doi.org/10.1016/S0885-2014(01)00037-5

Chawarska, K., Klin, A., & Volkmar, F. (2003). Automatic Attention Cueing Through Eye Movement in 2-Year-Old Children with Autism. *Child Development*, *74*(4), 1108–1122. https://doi.org/10.1111/1467-8624.00595

Chawarska, K., Macari, S., & Shic, F. (2013). Decreased spontaneous attention to social scenes in 6-month-old infants later diagnosed with autism spectrum disorders. *Biological Psychiatry*, *74*(3), 195–203. https://doi.org/10.1016/j.biopsych.2012.11.022

Chen, Y.-C., Colombatto, C., & Scholl, B. J. (2018). Looking into the future: An inward bias in aesthetic experience driven only by gaze cues. *Cognition*, *176*, 209–214. https://doi.org/10.1016/j.cognition.2018.02.010

Chen, Z., Thomas, R. H., & Chen, M. S. (2022). Do gaze and non-gaze stimuli trigger different spatial interference effects? It depends on stimulus perceivability. *Frontiers in Psychology*, *13*, 5373. https://doi.org/10.3389/fpsyg.2022.801151

Chita-Tegmark, M. (2016). Social attention in ASD: a Review and Meta-analysis of Eye-Tracking Studies. *Review Journal of Autism and Developmental Disorders*, *3*(3), 209–223. https://doi.org/10.1007/s40489-016-0077-x

Clohessy, A. B., Posner, M. I., Rothbart, M. K., & Vecera, S. P. (1991). The development of inhibition of return in early infancy. *Journal of Cognitive Neuroscience*, *3*(4), 345–350. https://doi.org/10.1162/jocn.1991.3.4.345

Colcombe, S. J., Kramer, A. F., Erickson, K. I., & Scalf, P. (2005). The implications of cortical recruitment and brain morphology for individual differences in inhibitory function in aging humans. *Psychology and Aging*, *20*(3), 363–375. https://doi.org/10.1037/0882-7974.20.3.363

Cole, G. G., & Millett, A. C. (2019). The closing of the theory of mind: A critique of perspective-taking. *Psychonomic Bulletin and Review*, *26*(6), 1787–1802. https://doi.org/10.3758/s13423-019-01657-y

Constantino, J. N., & Todd, R. D. (2003). Autistic Traits in the General Population: A Twin Study. *Archives of General Psychiatry*, *60*(5), 524–530.

https://doi.org/10.1001/ARCHPSYC.60.5.524

Conty, L., George, N., & Hietanen, J. K. (2016). Watching Eyes effects: When others meet the self. *Consciousness and Cognition*, *45*, 184–197. https://doi.org/10.1016/J.CONCOG.2016.08.016

Crouzet, S. M., Kirchner, H., & Thorpe, S. J. (2010). Fast saccades toward faces: face detection in just 100 ms. *Journal of Vision*, *10*(4), 1–17. https://doi.org/10.1167/10.4.16

Dalmaso, M., Castelli, L., & Galfano, G. (2020a). Early saccade planning cannot override oculomotor interference elicited by gaze and arrow distractors. *Psychonomic Bulletin and Review*, *27*(5), 990–997. https://doi.org/10.3758/s13423-020-01768-x

Dalmaso, M., Castelli, L., & Galfano, G. (2020b). Social modulators of gaze-mediated orienting of attention: A review. In *Psychonomic Bulletin and Review* (Vol. 27, Issue 5, pp. 833–855). Springer. https://doi.org/10.3758/s13423-020-01730-x

de Heering, A., & Rossion, B. (2015). Rapid categorization of natural face images in the infant right hemisphere. *ELife*, *4*(JUNE), 1–14. https://doi.org/10.7554/ELIFE.06564

Del Bianco, T., Falck-Ytter, T., Thorup, E., & Gredebäck, G. (2019). The Developmental Origins of Gaze-Following in Human Infants. In *Infancy* (Vol. 24, Issue 3, pp. 433–454). Blackwell Publishing Inc. https://doi.org/10.1111/infa.12276

Del Bianco, T., Mazzoni, N., Bentenuto, A., & Venuti, P. (2018). An Investigation of Attention to Faces and Eyes: Looking Time Is Task-Dependent in Autism Spectrum Disorder. *Frontiers in Psychology*, *9*(2629). https://doi.org/10.3389/fpsyg.2018.02629

Delgado, C. E. F., Mundy, P., Crowson, M., Markus, J., Yale, M., & Schwartz, H. (2002). Responding to Joint Attention and Language Development. *Journal of Speech, Language, and Hearing Research*, *45*(4), 715–719.

https://doi.org/10.1044/1092-4388(2002/057)

Dodd, M. D., Weiss, N., McDonnell, G. P., Sarwal, A., & Kingstone, A. (2012). Gaze cues influence memory…but not for long. *Acta Psychologica*, *141*(2), 270–275. https://doi.org/10.1016/j.actpsy.2012.06.003

Draheim, C., Mashburn, C. A., Martin, J. D., & Engle, R. W. (2019). Reaction time in differential and developmental research: A review and commentary on the problems and alternatives. *Psychological Bulletin*, *145*(5), 508–535. https://doi.org/10.1037/bul0000192

Edwards, S. G., Rudrum, M., McDonough, K. L., & Bayliss, A. P. (2022). The influence of social and emotional context on the gaze leading orienting effect. *Visual Cognition*, *30*(1–2), 54–69. https://doi.org/10.1080/13506285.2021.1980169

Edwards, S. G., Siebert, N., & Bayliss, A. P. (2020). Joint attention facilitates observed gaze direction discrimination. *Quarterly Journal of Experimental Psychology*, *73*(1), 80–90. https://doi.org/https://doi.org/10.1177/1747021819867901 DOI: 10.1177/1747021819867901

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting Visual Attention Between Objects and Locations: Evidence From Normal and Parietal Lesion Subjects. *Journal of Experimental Psychology: General*, *123*(2), 161–177. https://doi.org/10.1037/0096-3445.123.2.161

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology*, *99*(3), 225–234. https://doi.org/10.1016/0013-4694(96)95711-9

Emery, N. J. (2000). The eyes have it: The neuroethology, function and evolution of social gaze. In *Neuroscience and Biobehavioral Reviews* (Vol. 24, Issue 6, pp. 581–604). https://doi.org/10.1016/S0149-7634(00)00025-7

Erdfelder, E., Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191.

https://doi.org/10.3758/BF03193146

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics*, *40*(4), 225–240. https://doi.org/10.3758/BF03211502/METRICS

Farroni, T., Csibra, G., Simion, F., & Johnson, M. H. (2002). Eye contact detection in humans from birth. *Proceedings of the National Academy of Sciences of the United States of America*, *99*(14), 9602–9605. https://doi.org/10.1073/pnas.152159999

Farroni, T., Johnson, M. H., Brockbank, M., & Simion, F. (2000). Infants' use of gaze direction to cue attention: The importance of perceived motion. *Visual Cognition*, *7*(6), 705–718. https://doi.org/10.1080/13506280050144399

Farroni, T., Johnson, M. H., Menon, E., Zulian, L., Faraguna, D., & Csibra, G. (2005). Newborns' preference for face-relevant stimuli: Effects of contrast polarity. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(47), 17245–17250. https://doi.org/10.1073/pnas.0502205102

Farroni, T., Mansfield, E. M., Lai, C., & Johnson, M. H. (2003). Infants perceiving and acting on the eyes: Tests of an evolutionary hypothesis. *Journal of Experimental Child Psychology*, *85*(3), 199–212. https://doi.org/10.1016/S0022-0965(03)00022-5

Farroni, T., Massaccesi, S., Pividori, D., & Johnson, M. H. (2004). Gaze following in newborns. *Infancy*, *5*(1), 39–60. https://doi.org/10.1207/s15327078in0501_2

Fischer, J., Smith, H., Martinez-Pedraza, F., Carter, A. S., Kanwisher, N., & Kaldy, Z. (2016). Unimpaired attentional disengagement in toddlers with autism spectrum disorder. *Developmental Science*, *19*(6), 1095–1103. https://doi.org/10.1111/DESC.12386

Fletcher-Watson, S., Findlay, J. M., Leekam, S. R., & Benson, V. (2008). Rapid detection of person information in a naturalistic scene. *Perception*, *37*(4), 571–583. https://doi.org/10.1068/P5705

Franchini, M., Glaser, B., De Wilde, H. W., Gentaz, E., Eliez, S., & Schaer, M. (2017). Social orienting and joint attention in preschoolers with autism spectrum disorders. *PLoS ONE*, *12*(6), 1–14. https://doi.org/10.1371/journal.pone.0178859

Franchini, M., Glaser, B., Gentaz, E., Wood, H., Eliez, S., & Schaer, M. (2017). The effect of emotional intensity on responses to joint attention in preschoolers with an autism spectrum disorder. *Research in Autism Spectrum Disorders*, *35*, 13–24. https://doi.org/10.1016/j.rasd.2016.11.010

Freire, A., Eskritt, M., & Lee, K. (2004). Are eyes windows to a deceiver's soul? Children's use of another's eye gaze cues in a deceptive situation. *Developmental Psychology*, *40*(6), 1093–1104. https://doi.org/10.1037/0012-1649.40.6.1093

Friesen, C. K., & Kingstone, A. (1998). The eyes have it! reflexive orienting is triggered by nonpredictive gaze - download. *Psychonomic Bulletin & Review*, *5*(3), 490–495. https://doi.org/10.3758/BF03208827/METRICS

Frischen, A., Bayliss, A. P., & Tipper, S. P. (2007). Gaze Cueing of Attention: Visual Attention, Social Cognition, and Individual Differences. *Psychological Bulletin*, *133*(4), 694–724. https://doi.org/10.1037/0033-2909.133.4.694

Frischen, A., Smilek, D., Eastwood, J. D., & Tipper, S. P. (2007). Inhibition of return in response to gaze cues: The roles of time course and fixation cue. *Visual Cognition*, *15*(8), 881–895. https://doi.org/10.1080/13506280601112493

Frischen, A., & Tipper, S. P. (2004). Orienting attention via observed gaze shift evokes longer term inhibitory effects: Implications for social interactions, attention, and memory. *Journal of Experimental Psychology: General*, *133*(4), 516–533. https://doi.org/10.1037/0096-3445.133.4.516

Funes, M. J., Lupiáñez, J., & Humphreys, G. (2010). Analyzing the Generality of Conflict Adaptation Effects. *Journal of Experimental Psychology: Human Perception and Performance*, *36*(1), 147–161. https://doi.org/10.1037/a0017598

Funes, M. J., Lupiáñez, J., & Milliken, B. (2007). Separate Mechanisms Recruited by

Exogenous and Endogenous Spatial Cues: Evidence From a Spatial Stroop Paradigm. *Journal of Experimental Psychology: Human Perception and Performance*, *33*(2), 348–362. https://doi.org/10.1037/0096-1523.33.2.348

Georgescu, A. L., Kuzmanovic, B., Schilbach, L., Tepest, R., Kulbida, R., Bente, G., & Vogeley, K. (2013). Neural correlates of "social gaze" processing in high-functioning autism under systematic variation of gaze duration. *NeuroImage: Clinical*, *3*, 340–351. https://doi.org/10.1016/j.nicl.2013.08.014

Goren, C. C., Sarty, M., & Wu, P. Y. K. (1975). Visual following and pattern discrimination of face like stimuli by newborn infants. *Pediatrics*, *56*(4), 544–549. https://doi.org/10.1542/peds.56.4.544

Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the Use of Information: Strategic Control of Activation of Responses. *Journal of Experimental Psychology: General*, *121*(4), 480–506. https://doi.org/10.1037/0096-3445.121.4.480

Gregory, S. E. A., & Jackson, M. C. (2017). Joint attention enhances visual working memory. *Journal of Experimental Psychology: Learning Memory and Cognition*, *43*(2), 237–249. https://doi.org/10.1037/xlm0000294

Gregory, S. E. A., & Jackson, M. C. (2019). Barriers block the effect of joint attention on working memory: Perspective taking matters. *Journal of Experimental Psychology: Learning Memory and Cognition*, *45*(5), 795–806. https://doi.org/10.1037/xlm0000622

Guillon, Q., Hadjikhani, N., Baduel, S., & Rogé, B. (2014). Visual social attention in autism spectrum disorder: Insights from eye tracking studies. *Neuroscience & Biobehavioral Reviews*, *42*, 279–297. https://doi.org/10.1016/J.NEUBIOREV.2014.03.013

Hadders-Algra, M. (2022). Human face and gaze perception is highly context specific and involves bottom-up and top-down neural processing. *Neuroscience and Biobehavioral Reviews*, *132*, 304–323.

https://doi.org/10.1016/j.neubiorev.2021.11.042

Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *36*(1), 5–25. https://doi.org/10.1007/S10803-005-0039-0/TABLES/1

Hedge, C., Powell, G., & Sumner, P. (2018). The mapping between transformed reaction time costs and models of processing in aging and cognition. *Psychology and Aging*, *33*(7), 1093–1104. https://doi.org/10.1037/pag0000298

Heider, F., & Simmel, M. (1944). An Experimental Study of Apparent Behavior. *Source: The American Journal of Psychology*, *57*(2), 243–259.

Hemmerich, K., Narganes-Pineda, C., Marotta, A., Martín-Arévalo, E., Jiménez, L., & Lupiáñez, J. (2022). Gaze elicits social and nonsocial attentional orienting: An interplay of shared and unique conflict processing mechanisms. *Journal of Experimental Psychology: Human Perception and Performance*, *48*(8), 824–841. https://doi.org/10.1037/xhp0001015

Hergovich, A., & Oberfichtner, B. (2016). Magic and misdirection: The influence of social cues on the allocation of visual attention while watching a cups-and-balls routine. *Frontiers in Psychology*, *7*(MAY), 761. https://doi.org/10.3389/fpsyg.2016.00761

Heyes, C. (2014). False belief in infancy: a fresh look. *Developmental Science*, *17*(5), 647–659. https://doi.org/10.1111/desc.12148

Hietanen, J. K., Myllyneva, A., Helminen, T. M., Lyyra, P., & Hietanen. (2016). The Effects of Genuine Eye Contact on Visuospatial and Selective Attention. *Journal of Experimental Psychology : General*. https://doi.org/http://dx.doi.org/10.1037/xge0000199

Hietanen, J. K., Nummenmaa, L., Nyman, M. J., Parkkola, R., & Hämäläinen, H. (2006). Automatic attention orienting by social and symbolic cues activates different neural networks: An fMRI study. *NeuroImage*, *33*(1), 406–413.

https://doi.org/10.1016/j.neuroimage.2006.06.048

Hommel, B. (1993). The relationship between stimulus processing and response selection in the Simon task: Evidence for a temporal overlap. *Psychological Research*, *55*(4), 280–290. https://doi.org/10.1007/BF00419688

Hood, B. M., Willen, J. D., & Driver, J. (1998). *Adult's eyes trigger shifts of visual attention in human infants*. https://journals.sagepub.com/doi/pdf/10.1111/1467-9280.00024

Hooker, C. I., Paller, K. A., Gitelman, D. R., Parrish, T. B., Mesulam, M. M., & Reber, P. J. (2003). Brain networks for analyzing eye gaze. *Cognitive Brain Research*, *17*(2), 406–418. https://doi.org/10.1016/S0926-6410(03)00143-5

Hudson, M., Nijboer, T. C. W., & Jellema, T. (2012). Implicit social learning in relation to autistic-like traits. *Journal of Autism and Developmental Disorders*, *42*(12), 2534–2545. https://doi.org/10.1007/S10803-012-1510-3/FIGURES/2

Ishikawa, K., Oyama, T., & Okubo, M. (2021). The malfunction of domain-specific attentional process in social anxiety: attentional process of social and non-social stimuli. *Cognition and Emotion*, *0*(0), 1–12. https://doi.org/10.1080/02699931.2021.1935217

Ishikawa, K., Oyama, T., Tanaka, Y., & Okubo, M. (2022). *Can you make eye contact ?: Perceiving social gaze produces the reversed congruency effect*. https://doi.org/https://doi.org/10.31234/osf.io/hbn2x

Ishikawa, M., Haensel, J. X., Smith, T. J., Senju, A., & Itakura, S. (2020). Affective priming enhances gaze cueing effect. *Journal of Experimental Psychology: Human Perception and Performance*. https://doi.org/10.1037/xhp0000880

Itier, R. J., & Batty, M. (2009). Neural bases of eye and gaze processing: The core of social cognition. In *Neuroscience and Biobehavioral Reviews* (Vol. 33, Issue 6, pp. 843–863). https://doi.org/10.1016/j.neubiorev.2009.02.004

Jaswal, S., & Logie, R. H. (2013). The contextual interference effect in visual feature binding: What does it say about the role of attention in binding? *Quarterly Journal of Experimental Psychology*, *66*(4), 687–704. https://doi.org/10.1080/17470218.2012.712540

Jaworski, J. L. B., & Eigsti, I. M. (2015). Low-level visual attention and its relation to joint attention in autism spectrum disorder. *Child Neuropsychology*, *23*(3), 316–331. https://doi.org/10.1080/09297049.2015.1104293

Jingling, L., Lin, H. F., Tsai, C. J., & Lin, C. C. (2015). Development of inhibition of return for eye gaze in adolescents. *Journal of Experimental Child Psychology*, *137*, 76–84. https://doi.org/10.1016/j.jecp.2015.04.001

Johnson, M. H., Dziurawiec, S., Ellis, H., & Morton, J. (1991). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition*, *40*(1–2), 1–19. https://doi.org/10.1016/0010-0277(91)90045-6

Johnson, M. H., Griffin, R., Csibra, G., Halit, H., Farroni, T., De Haan, M., Tucker, L. A., Baron-Cohen, S., & Richards, J. (2005). The emergence of the social brain network: Evidence from typical and atypical development. *Development and Psychopathology*, *17*(3), 599–619. https://doi.org/10.1136/bmj.38519.678148.8F

Jones, S. (2015). The mediating effects of facial expression on spatial interference between gaze direction and gaze location. *Journal of General Psychology*, *142*(2), 106–117. https://doi.org/10.1080/00221309.2015.1009822

Kano, F., Furuichi, T., Hashimoto, C., Krupenye, C., Leinwand, J. G., Hopper, L. M., Martin, C. F., Otsuka, R., & Tajima, T. (2022). What is unique about the human eye? Comparative image analysis on the external eye morphology of human and nonhuman great apes. *Evolution and Human Behavior*, *43*(3), 169–180. https://doi.org/10.1016/j.evolhumbehav.2021.12.004

Kasari, C., Gulsrud, A. C., Shire, S. Y., & Strawbridge, C. (2022). The JASPER model for children with autism: Promoting Joint Attention, Symbolic Play, Engagement, and Regulation. *The JASPER Model for Children with Autism: Promoting Joint Attention, Symbolic Play, Engagement, and Regulation.*

https://es.scribd.com/document/629413401/The-JASPER-Model-for-Children-With-Autism-Promoting-Joint-Attention-Symbolic-Play-Engagement-And-Regulation#

Kasari, C., Paparella, T., Freeman, S., & Jahromi, L. B. (2008). Language outcome in autism: Randomized comparison of joint attention and play interventions. *Journal of Consulting and Clinical Psychology*, *76*(1), 125–137. https://doi.org/10.1037/0022-006X.76.1.125

Kikuchi, Y., Senju, A., Tojo, Y., Osanai, H., & Hasegawa, T. (2009). Faces Do Not Capture Special Attention in Children With Autism Spectrum Disorder: A Change Blindness Study. *Child Development*, *80*(5), 1421–1433. https://doi.org/10.1111/J.1467-8624.2009.01342.X

Kirchner, J. C., Hatri, A., Heekeren, H. R., & Dziobek, I. (2011). Autistic symptomatology, face processing abilities, and eye fixation patterns. *Journal of Autism and Developmental Disorders*, *41*(2), 158–167. https://doi.org/10.1007/S10803-010-1032-9

Kisilevsky, B. S., Hains, S. M. J., Lee, K., Xie, X., Huang, H., Ye, H. H., Zhang, K., & Wang, Z. (2003). Effects of experience on fetal voice recognition. *Psychological Science*, *14*(3), 220–224. https://doi.org/10.1111/1467-9280.02435/ASSET/IMAGES/LARGE/10.1111_1467-9280.02435-FIG1.JPEG

Kobayashi, H., & Kohshima, S. (2001). Unique morphology of the human eye and its adaptive meaning: Comparative studies on external morphology of the primate eye. *Journal of Human Evolution*, *40*(5), 419–435. https://doi.org/10.1006/jhev.2001.0468

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional Overlap: Cognitive Basis for Stimulus-Response Compatibility-A Model and Taxonomy. *Psychological Review*, *97*(2), 253–270. https://doi.org/10.1037/0033-295X.97.2.253

Kuhn, G., Benson, V., Fletcher-Watson, S., Kovshoff, H., McCormick, C. A., Kirkby, J.,

& Leekam, S. R. (2010). Eye movements affirm: Automatic overt gaze and arrow cueing for typical adults and adults with autism spectrum disorder. *Experimental Brain Research*, *201*(2), 155–165. https://doi.org/10.1007/s00221-009-2019-7

Kuzmanovic, B., Rigoux, L., & Vogeley, K. (2019). Brief Report: Reduced Optimism Bias in Self-Referential Belief Updating in High-Functioning Autism. *Journal of Autism and Developmental Disorders*, *49*(7), 2990–2998. https://doi.org/10.1007/S10803-016-2940-0

Lakens, D., & Etz, A. J. (2017). Too True to be Bad: When Sets of Studies With Significant and Nonsignificant Findings Are Probably True. *Social Psychological and Personality Science*, *8*(8), 875–881. https://doi.org/10.1177/1948550617693058

Langton, S. R. H. (2000). *The mutual influence of gaze and head orientation in the analysis of social attention direction*. *53*(3), 825–845. https://doi.org/10.1080/713755908

Langton, S. R. H., Honeyman, H., & Tessler, E. (2004). The influence of head contour and nose angle on the perception of eye-gaze direction. *Perception and Psychophysics*, *66*(5), 752–771. https://doi.org/10.3758/BF03194970

Lee, K., Eskritt, M., Symons, L. A., & Muir, D. (1998). Children's use of triadic eye gaze information for "mind reading." In *Developmental Psychology* (Vol. 34, pp. 525–539). American Psychological Association. https://doi.org/10.1037/0012-1649.34.3.525

Leekam, S., Baron-Cohen, S., Perrett, D., Milders, M., & Brown, S. (1997). Eye-direction detection: A dissociation between geometric and joint attention skills in autism. *British Journal of Developmental Psychology*, *15*(1), 77–95. https://doi.org/10.1111/j.2044-835x.1997.tb00726.x

Liao, M. J., & Wang, S. H. (2015). Exploring the role of stimulus code–response modality compatibility on the spatial Stroop effect. *Ergonomics*, *58*(8), 1372–

1387. https://doi.org/10.1080/00140139.2015.1005169

Lobmaier, J. S., Fischer, M. H., & Schwaninger, A. (2006). Objects capture perceived gaze direction. *Experimental Psychology*, *53*(2), 117–122. https://doi.org/10.1027/1618-3169.53.2.117

Lobmaier, J. S., & Perrett, D. I. (2011). The world smiles at me: self-referential positivity bias when interpreting direction of attention. *Cognition & Emotion*, *25*(2), 334–341. https://doi.org/10.1080/02699931003794557

Lu, C. hui, & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. In *Psychonomic Bulletin & Review* (Vol. 2, Issue 2, pp. 174–207). https://doi.org/10.3758/BF03210959

Lundqvist, D., Flykt, A., & Öhman, A. (1998). *Karolinska Directed Emotional Faces* (APA PsycTests (ed.)). https://doi.org/https://doi.org/10.1037/t27732-000

Lupiáñez, J., Martín-Arévalo, E., & Chica, A. B. (2013). Is inhibition of return due to attentional disengagement or to a detection cost? The detection cost theory of IOR. *Psicologica*, *34*(2), 221–252.

Macinska, S. T. (2019). *Implicit social cognition in autism spectrum disorder* [University of Hull]. https://hull-repository.worktribe.com/output/4221941

Manera, V., Elena, M. R., Bayliss, A. P., & Becchio, C. (2014). When seeing is more than looking: Intentional gaze modulates object desirability. *Emotion*, *14*(4), 824–832. https://doi.org/10.1037/a0036258

Marotta, A., Aranda-Martín, B., De Cono, M., Ballesteros-Duperón, M. Á., Casagrande, M., & Lupiáñez, J. (2022). Integration of Facial Expression and Gaze Direction in Individuals with a High Level of Autistic Traits. *International Journal of Environmental Research and Public Health*, *19*(5), 2798. https://doi.org/10.3390/ijerph19052798

Marotta, A., Casagrande, M., & Lupiáñez, J. (2013). Object-based attentional effects in response to eye-gaze and arrow cues. *Acta Psychologica*, *143*(3), 317–321. https://doi.org/10.1016/j.actpsy.2013.04.006

Marotta, A., Lupiáñez, J., Martella, D., & Casagrande, M. (2012). Eye gaze versus arrows as spatial cues: Two qualitatively different modes of attentional selection. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(2), 326–335. https://doi.org/10.1037/a0023959

Marotta, A., Lupiáñez, J., Román-Caballero, R., Narganes-Pineda, C., & Martín-Arévalo, E. (2019). Are eyes special? Electrophysiological and behavioural evidence for a dissociation between eye-gaze and arrows attentional mechanisms. *Neuropsychologia*, *129*, 146–152. https://doi.org/10.1016/j.neuropsychologia.2019.03.017

Marotta, A., Pasini, A., Ruggiero, S., Maccari, L., Rosa, C., Lupiáñez, J., & Casagrande, M. (2013). Inhibition of Return in Response to Eye Gaze and Peripheral Cues in Young People with Asperger's Syndrome. *Journal of Autism and Developmental Disorders*, *43*(4), 917–923. https://doi.org/10.1007/s10803-012-1636-3

Marotta, A., Román-Caballero, R., & Lupiáñez, J. (2018). Arrows don't look at you: Qualitatively different attentional mechanisms triggered by gaze and arrows. *Psychonomic Bulletin and Review*, *25*(6), 2254–2259. https://doi.org/10.3758/s13423-018-1457-2

Martín-Arévalo, E., Kingstone, A., & Lupiáñez, J. (2013). Is "Inhibition of Return" due to the inhibition of the return of attention? *Quarterly Journal of Experimental Psychology*, *66*(2), 347–359. https://doi.org/10.1080/17470218.2012.711844

Mastergeorge, A. M., Kahathuduwa, C., & Blume, J. (2020). Eye-Tracking in Infants and Young Children at Risk for Autism Spectrum Disorder: A Systematic Review of Visual Stimuli in Experimental Paradigms. *Journal of Autism and Developmental Disorders*, 1–22. https://doi.org/10.1007/s10803-020-04731-w

Materna, S., Dicke, P. W., & Thier, P. (2008). Dissociable roles of the superior temporal sulcus and the intraparietal sulcus in joint attention: A functional magnetic resonance imaging study. *Journal of Cognitive Neuroscience*, *20*(1), 108–119. https://doi.org/10.1162/jocn.2008.20008

Mckay, K. T., Grainger, S. A., Coundouris, S. P., Skorich, D. P., Phillips, L. H., & Henry, J. D. (2021). Visual Attentional Orienting by Eye Gaze: A Meta-Analytic Review of the Gaze-Cueing Effect. *Psychological Bulletin*, *147*, *12*(February), 1269–1289. https://doi.org/10.1037/bul0000353

Meltzoff, A. N., & Brooks, R. (2008). Self-Experience as a Mechanism for Learning About Others: A Training Study in Social Cognition. *Developmental Psychology*, *44*(5), 1257–1265. https://doi.org/10.1037/A0012888

Mezulis, A. H., Abramson, L. Y., Hyde, J. S., & Hankin, B. L. (2004). Is there a universal positivity bias in attributions? A meta-analytic review of individual, developmental, and cultural differences in the self-serving attributional bias. *Psychological Bulletin*, *130*(5), 711–747. https://doi.org/10.1037/0033-2909.130.5.711

Moll, H., & Tomasello, M. (2004). 12- and 18-month-old infants follow gaze to spaces behind barriers. *Developmental Science*, *7*(1), F1–F9. https://doi.org/10.1111/j.1467-7687.2004.00315.x

Morales, M., Mundy, P., & Rojas, J. (1998). Following the direction of gaze and language development in 6-month-olds. *Infant Behavior and Development*, *21*(2), 373–377. https://doi.org/10.1016/S0163-6383(98)90014-5

Morton, J., & Johnson, M. H. (1991). CONSPEC and CONLERN: A two-process theory of infant face recognition. *Psychological Review*, *98*(2), 164–181. https://doi.org/10.1037/0033-295X.98.2.164

Mosconi, M. W., Mack, P. B., McCarthy, G., & Pelphrey, K. A. (2005). Taking an "intentional stance" on eye-gaze shifts: A functional neuroimaging study of social perception in children. *NeuroImage*, *27*(1), 247–252. https://doi.org/10.1016/j.neuroimage.2005.03.027

Mundy, P. (2018). A review of joint attention and social-cognitive brain systems in typical development and autism spectrum disorder. *European Journal of Neuroscience*, *47*(6), 497–514. https://doi.org/10.1111/ejn.13720

Mundy, P., Block, J., Delgado, C., Pomares, Y., Van Hecke, A. V., & Parlade, M. V. (2007). Individual differences and the development of joint attention in infancy. *Child Development*, *78*(3), 938–954. https://doi.org/10.1111/j.1467-8624.2007.01042.x

Mundy, P., & Bullen, J. (2022). The Bidirectional Social-Cognitive Mechanisms of the Social-Attention Symptoms of Autism. *Frontiers in Psychiatry*, *12*, 752274. https://doi.org/10.3389/fpsyt.2021.752274

Mundy, P., & Newell, L. (2007). Attention, joint attention & social cognition. *Social Cognition*, *16*(January 2008), 269–274. https://doi.org/10.1111/j.1467-8721.2007.00518.x.Attention

Narganes-Pineda, C., Chica, A. B., Lupiáñez, J., & Marotta, A. (2022). Explicit vs. implicit spatial processing in arrow vs. eye-gaze spatial congruency effects. *Psychological Research*, *87*(0123456789), 242–259. https://doi.org/10.1007/s00426-022-01659-x

Nation, K., & Penny, S. (2008). Sensitivity to eye gaze in autism: Is it normal? Is it automatic? Is it social? *Development and Psychopathology*, *20*(1), 79–97. https://doi.org/10.1017/S0954579408000047

Face processing in autism spectrum disorders: From brain regions to brain networks, 71 Neuropsychologia 201 (2015). https://doi.org/10.1016/j.neuropsychologia.2015.03.029

Okumura, Y., Kanakogi, Y., Kobayashi, T., & Itakura, S. (2017). Individual differences in object-processing explain the relationship between early gaze-following and later language development. *Cognition*, *166*, 418–424. https://doi.org/10.1016/j.cognition.2017.06.005

Ozonoff, S., Pennington, B. F., & Rogers, S. J. (1990). Are there Emotion Perception Deficits in Young Autistic Children? *Journal of Child Psychology and Psychiatry*, *31*(3), 343–361. https://doi.org/10.1111/J.1469-7610.1990.TB01574.X

Pahl, S., & Eiser, J. R. (2006). Valence, Comparison Focus and Self-Positivity Biases. *Https://Doi.Org/10.1027/1618-3169.52.4.303*, *52*(4), 303–309. https://doi.org/10.1027/1618-3169.52.4.303

Pecchinenda, A., & Petrucci, M. (2021). Emotion first: children prioritize emotional faces in gaze-cued attentional orienting. *Psychological Research*, *3*(1), 101–111. https://doi.org/10.1007/s00426-019-01237-8

Pelphrey, K. A., Morris, J. P., & McCarthy, G. (2004). Grasping the intentions of others: The perceived intentionality of an action influences activity in the superior temporal sulcus during social perception. *Journal of Cognitive Neuroscience*, *16*(10), 1706–1716. https://doi.org/10.1162/0898929042947900

Pelphrey, K. A., Morris, J. P., & McCarthy, G. (2005). Neural basis of eye gaze processing deficits in autism. *Brain*, *128*(5), 1038–1048. https://doi.org/10.1093/brain/awh404

Pelphrey, K. A., Sasson, N. J., Reznick, J. S., Paul, G., Goldman, B. D., & Piven, J. (2002). Visual Scanning of Faces in Autism. *Journal of Autism and Developmental Disorders*, *32*(4), 249–261. https://doi.org/10.1023/A:1016374617369/METRICS

Pelphrey, K. A., Singerman, J. D., Allison, T., & McCarthy, G. (2003). Brain activation evoked by perception of gaze shifts: The influence of context. *Neuropsychologia*, *41*(2), 156–170. https://doi.org/10.1016/S0028-3932(02)00146-X

Phillips, J., Ong, D. C., Surtees, A. D. R., Xin, Y., Williams, S., Saxe, R., & Frank, M. C. (2015). A second look at automatic theory of mind: Reconsidering kovács, téglás, and endress (2010). *Psychological Science*, *26*(9), 1353–1367. https://doi.org/10.1177/0956797614558717

Piven, J., Palmer, P., Jacobi, D., Childress, D., & Arndt, S. (1997). Broader autism phenotype: evidence from a family history study of multiple-incidence autism families. *The American Journal of Psychiatry*, *154*(2), 185–190.

https://doi.org/10.1176/AJP.154.2.185

Poljac, E., de-Wit, L., & Wagemans, J. (2012). Perceptual wholes can reduce the conscious accessibility of their parts. *Cognition*, *123*(2), 308–312. https://doi.org/10.1016/J.COGNITION.2012.01.001

Porter, R. H., & Winberg, J. (1999). Unique salience of maternal breast odors for newborn infants. *Neuroscience & Biobehavioral Reviews*, *23*(3), 439–449. https://doi.org/10.1016/S0149-7634(98)00044-X

Posner, M. I. (1980). Orienting of attention. *The Quarterly Journal of Experimental Psychology*, *32*(1), 3–25. https://doi.org/10.1080/00335558008248231

Purcell, D. G., & Stewart, A. L. (1988). The face-detection effect: Configuration enhances detection. *Perception & Psychophysics*, *43*(4), 355–366. https://doi.org/10.3758/BF03208806/METRICS

Putman, P., Hermans, E., & Honk, J. Van. (2006). *Anxiety Meets Fear in Perception of Dynamic Expressive Gaze*. *6*(1), 94–102. https://doi.org/10.1037/1528-3542.6.1.94

Quadflieg, S., Mason, M. F., & Neil Macrae, C. (2004). The owl and the pussycat: Gaze cues and visuospatial orienting. *Psychonomic Bulletin and Review*, *11*(5), 826–831. https://doi.org/10.3758/BF03196708

R Core Team (2021). (n.d.). *R: A language and environment for statistical computing.*

Rasmussen, C. E., & Jiang, Y. V. (2019). Judging social interaction in the Heider and Simmel movie. *Quarterly Journal of Experimental Psychology*, *72*(9), 2350–2361. https://doi.org/10.1177/1747021819838764/ASSET/IMAGES/LARGE/10.1177_1747021819838764-FIG5.JPEG

Reid, V. M., Dunn, K., Young, R. J., Amu, J., Donovan, T., & Reissland, N. (2017). The Human Fetus Preferentially Engages with Face-like Visual Stimuli. *Current Biology*, *27*(12), 1825-1828.e3. https://doi.org/10.1016/j.cub.2017.05.044

Rellecke, J., Sommer, W., & Schacht, A. (2012). Does processing of emotional facial expressions depend on intention? Time-resolved evidence from event-related brain potentials. *Biological Psychology*, *90*(1), 23–32. https://doi.org/10.1016/j.biopsycho.2012.02.002

Ricciardelli, P., Carcagno, S., Vallar, G., & Bricolo, E. (2013). Is gaze following purely reflexive or goal-directed instead? Revisiting the automaticity of orienting attention by gaze cues. *Experimental Brain Research*, *224*(1), 93–106. https://doi.org/10.1007/s00221-012-3291-5

Ristic, J., Friesen, C. K., & Kingstone, A. (2002). Are eyes special? It depends on how you look at it. *Psychonomic Bulletin & Review*, *3*, 507–513.

Ristic, J., & Kingstone, A. (2012). A new form of human spatial attention: Automated symbolic orienting. *Https://Doi.Org/10.1080/13506285.2012.658101*, *20*(3), 244–264. https://doi.org/10.1080/13506285.2012.658101

Ristic, J., Mottron, L., Friesen, C. K., Iarocci, G., Burack, J. A., & Kingstone, A. (2005). Eyes are special but not for everyone: The case of autism. *Cognitive Brain Research*, *24*(3), 715–718. https://doi.org/10.1016/j.cogbrainres.2005.02.007

Röder, B., Ley, P., Shenoy, B. H., Kekunnaya, R., & Bottari, D. (2013). Sensitive periods for the functional specialization of the neural system for human face processing. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(42), 16760–16765. https://doi.org/10.1073/PNAS.1309963110

Román-Caballero, R., Marotta, A., & Lupiáñez, J. (2021a). Target-Background Segregation in a Spatial Interference Paradigm Reveals Shared and Specific Attentional Mechanisms Triggered by Gaze and Arrows. *Journal of Experimental Psychology. Human Perception and Performance*, *47*(11), 1561–1573. https://doi.org/10.1037/XHP0000953

Román-Caballero, R., Marotta, A., & Lupiáñez, J. (2021b). Spatial interference triggered by gaze and arrows. The role of target background on spatial interference. *Psicológica Journal*, *42*(2), 192–209. https://doi.org/10.2478/psicolj-2021-0010

Ruch, W., Hofmann, J., Platt, T., & Proyer, R. (2014). The state-of-the art in gelotophobia research: A review and some theoretical extensions. *Humor*, *27*(1), 23–45. https://doi.org/10.1515/HUMOR-2013-0046/MACHINEREADABLECITATION/RIS

Senju, A., Csibra, G., & Johnson, M. H. (2008). Understanding the referential nature of looking: Infants' preference for object-directed gaze. *Cognition*, *108*(2), 303–319. https://doi.org/10.1016/J.COGNITION.2008.02.009

Senju, A., & Johnson, M. H. (2009). The eye contact effect: mechanisms and development. In *Trends in Cognitive Sciences* (Vol. 13, Issue 3, pp. 127–134). Elsevier Current Trends. https://doi.org/10.1016/j.tics.2008.11.009

Sepeta, L., Tsuchiya, N., Davies, M. S., Sigman, M., Bookheimer, S. Y., & Dapretto, M. (2012). Abnormal social reward processing in autism as indexed by pupillary responses to happy faces. *Journal of Neurodevelopmental Disorders*, *4*(1). https://doi.org/10.1186/1866-1955-4-17

Shaffer, R. C., Pedapati, E. V., Shic, F., Gaietto, K., Bowers, K., Wink, L. K., & Erickson, C. A. (2017). Brief Report: Diminished Gaze Preference for Dynamic Social Interaction Scenes in Youth with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *47*(2), 506–513. https://doi.org/10.1007/S10803-016-2975-2/FIGURES/2

Shah, P., Gaule, A., Bird, G., & Cook, R. (2013). Robust orienting to protofacial stimuli in autism. *Current Biology : CB*, *23*(24). https://doi.org/10.1016/J.CUB.2013.10.034

Shepherd, S. V. (2010). Following gaze: Gaze-following behavior as a window into social cognition. *Frontiers in Integrative Neuroscience*, *4*(MARCH 2010). https://doi.org/10.3389/fnint.2010.00005

Shultz, S., Klin, A., & Jones, W. (2018). Neonatal Transitions in Social Behavior and

Their Implications for Autism. *Trends in Cognitive Sciences*, *22*(5), 452–469. https://doi.org/10.1016/J.TICS.2018.02.012

Simion, F., Valenza, E., Cassia, V. M., Turati, C., & Umiltà, C. (2002). Newborns' preference for up-down asymmetrical configurations. *Developmental Science*, *5*(4), 427–434. https://doi.org/10.1111/1467-7687.00237

Simion, F., Valenza, E., Umiltà, C., & Dalla Barba, B. (1998). Preferential Orienting to Faces in Newborns: A Temporal-Nasal Asymmetry. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(5), 1399–1405. https://doi.org/10.1037/0096-1523.24.5.1399

Siposova, B., & Carpenter, M. (2019). A new look at joint attention and common knowledge. *Cognition*, *189*, 260–274. https://doi.org/10.1016/j.cognition.2019.03.019

Smith, L. B. (2005). Cognition as a dynamic system: Principles from embodiment. *Developmental Review*, *25*(3–4), 278–298. https://doi.org/10.1016/J.DR.2005.11.001

Sowell, E. R., Thompson, P. M., Leonard, C. M., Welcome, S. E., Kan, E., & Toga, A. W. (2004). Longitudinal mapping of cortical thickness and brain growth in normal children. *Journal of Neuroscience*, *24*(38), 8223–8231. https://doi.org/10.1523/JNEUROSCI.1798-04.2004

Spiker, D., Lotspeich, L. J., Dimiceli, S., Myers, R. M., & Risch, N. (2002). Behavioral phenotypic variation in autism multiplex families: Evidence for a continuous severity gradient. *American Journal of Medical Genetics*, *114*(2), 129–136. https://doi.org/10.1002/AJMG.10188

Striano, T., & Reid, V. M. (2006). Social cognition in the first year. In *Trends in Cognitive Sciences* (Vol. 10, Issue 10, pp. 471–476). https://doi.org/10.1016/j.tics.2006.08.006

Tanaka, Y., Ishikawa, K., Oyama, T., & Okubo, M. (2022). Face inversion does not affect the reversed congruency effect of gaze. *Psychonomic Bulletin & Review*

2022, *1*, 1–9. https://doi.org/10.3758/S13423-022-02208-8

Taylor, M. J., Edmonds, G. E., McCarthy, G., & Allison, T. (2001). Eyes first! Eye processing develops before face processing in children. *NeuroReport*, *12*(8), 1671–1676. https://doi.org/10.1097/00001756-200106130-00031

Tipples, J., & Pecchinenda, A. (2019). A closer look at the size of the gaze-liking effect : A preregistered replication. *Cognition and Emotion*, *33*(3), 623–629.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: the origins of cultural cognition. *Behavioral and Brain Sciences*, *28*(5), 675–735. https://doi.org/10.1017/S0140525X05000129

Tomasello, M., Hare, B., Lehmann, H., & Call, J. (2007). Reliance on head versus eyes in the gaze following of great apes and human infants: the cooperative eye hypothesis. *Journal of Human Evolution*, *52*(3), 314–320. https://doi.org/10.1016/J.JHEVOL.2006.10.001

Torres-Marín, J., Carretero-Dios, H., Acosta, A., & Lupiáñez, J. (2017). Eye contact and fear of being laughed at in a gaze discrimination task. *Frontiers in Psychology*, *8*(NOV), 1–14. https://doi.org/10.3389/fpsyg.2017.01954

Vaidya, C. J., Foss-Feig, J., Shook, D., Kaplan, L., Kenworthy, L., & Gaillard, W. D. (2011). Controlling attention to gaze and arrows in childhood: An fMRI study of typical development and Autism Spectrum Disorders. *Developmental Science*, *14*(4), 911–924. https://doi.org/10.1111/j.1467-7687.2011.01041.x

Vernetti, A., Ganea, N., Tucker, L., Charman, T., Johnson, M. H., & Senju, A. (2018). Infant neural sensitivity to eye gaze depends on early experience of gaze communication. *Developmental Cognitive Neuroscience*, *34*, 1–6. https://doi.org/10.1016/J.DCN.2018.05.007

Vettori, S., Dzhelyova, M., Van der Donck, S., Jacques, C., Van Wesemael, T., Steyaert, J., Rossion, B., & Boets, B. (2020). Combined frequency-tagging EEG and eye tracking reveal reduced social bias in boys with autism spectrum disorder. *Cortex*, *125*, 135–148. https://doi.org/10.1016/j.cortex.2019.12.013

Vettori, S., Van der Donck, S., Nys, J., Moors, P., Van Wesemael, T., Steyaert, J., Rossion, B., Dzhelyova, M., & Boets, B. (2020). Combined frequency-tagging EEG and eye-tracking measures provide no support for the "excess mouth/diminished eye attention" hypothesis in autism. *Molecular Autism*, *11*(1), 1–22. https://doi.org/10.1186/S13229-020-00396-5/FIGURES/2

Virzi, R. A., & Egeth, H. E. (1985). Toward a translational model of Stroop interference. *Memory & Cognition*, *13*(4), 304–319. https://doi.org/10.3758/BF03202499

Vlamings, P. H. J. M., Stauder, J. E. A., Van Son, I. A. M., & Mottron, L. (2005). Atypical visual orienting to gaze- and arrow-cues in adults with high functioning autism. *Journal of Autism and Developmental Disorders*, *35*(3), 267–277. https://doi.org/10.1007/s10803-005-3289-y

Volkmar, F. R. (2011). Understanding the social brain in autism. *Developmental Psychobiology*, *53*(5), 428–434. https://doi.org/10.1002/DEV.20556

Wagenmakers, E. J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., Selker, R., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Rouder, J. N., & Morey, R. D. (2018). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychonomic Bulletin and Review*, *25*(1), 35–57. https://doi.org/10.3758/s13423-017-1343-3

Wagenmakers, E. J., Wetzels, R., Borsboom, D., & van der Maas, H. L. J. (2011). Why Psychologists Must Change the Way They Analyze Their Data: The Case of Psi: Comment on Bem (2011). *Journal of Personality and Social Psychology*, *100*(3), 426–432. https://doi.org/10.1037/a0022790

Walen, P. J., Kagan, J., Cook, R. G., Davis, F. C., Kim, H., Polis, S., McLaren, D. G., Somerville, L. H., McLean, A. A., Maxwell, J. S., & Johnstone, T. (2004). Human amygdala responsivity to masked fearful eye whites. *Science (New York, N.Y.)*, *306*(5704), 2061. https://doi.org/10.1126/SCIENCE.1103617

Wallace, S., Coleman, M., Pascalis, O., & Bailey, A. (2006). A Study of Impaired Judgment of Eye-Gaze Direction and Related Face-Processing Deficits in

Autism Spectrum Disorders. *Http://Dx.Doi.Org/10.1068/P5442*, *35*(12), 1651–1664. https://doi.org/10.1068/P5442

Weeks, S. J., & Hobson, R. P. (1987). THE SALIENCE OF FACIAL EXPRESSION FOR AUTISTIC CHILDREN. *Journal of Child Psychology and Psychiatry*, *28*(1), 137–152. https://doi.org/10.1111/j.1469-7610.1987.tb00658.x

Wheelwright, S., Auyeung, B., Allison, C., & Baron-Cohen, S. (2010). Defining the broader, medium and narrow autism phenotype among parents using the Autism Spectrum Quotient (AQ). *Molecular Autism*, *1*(1), 1–9. https://doi.org/10.1186/2040-2392-1-10

Wicker, B., Michel, F., Henaff, M. A., & Decety, J. (1998). Brain regions involved in the perception of gaze: a PET study. *NeuroImage*, *8*(2), 221–227. https://doi.org/10.1006/NIMG.1998.0357

Williamson, S., Craig, J., & Slinger, R. (2008). Exploring the relationship between measures of self-esteem and psychological adjustment among adolescents with Asperger syndrome. *Autism : The International Journal of Research and Practice*, *12*(4), 391–402. https://doi.org/10.1177/1362361308091652

Wilson, C. E., Brock, J., & Palermo, R. (2010). Attention to social stimuli and facial identity recognition skills in autism spectrum disorder. *Journal of Intellectual Disability Research*, *54*(12), 1104–1115. https://doi.org/10.1111/J.1365-2788.2010.01340.X

Yankouskaya, A., Booth, D. A., & Humphreys, G. (2012). Interactions between facial emotion and identity in face processing: Evidence based on redundancy gains. *Attention, Perception, and Psychophysics*, *74*(8), 1692–1711. https://doi.org/10.3758/S13414-012-0345-5

Zhang, X., Dalmaso, M., Castelli, L., Fiorese, A., Lan, Y., Sun, B., Fu, S., & Galfano, G. (2020). Social attention across borders: A cross-cultural investigation of gaze cueing elicited by same- and other-ethnicity faces. *British Journal of Psychology*, bjop.12476. https://doi.org/10.1111/bjop.12476

Zhao, S., Uono, S., Yoshimura, S., & Toichi, M. (2015). Is impaired joint attention present in non-clinical individuals with high autistic traits? *Molecular Autism*, *6*(1), 1–9. https://doi.org/10.1186/S13229-015-0059-3/TABLES/1

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