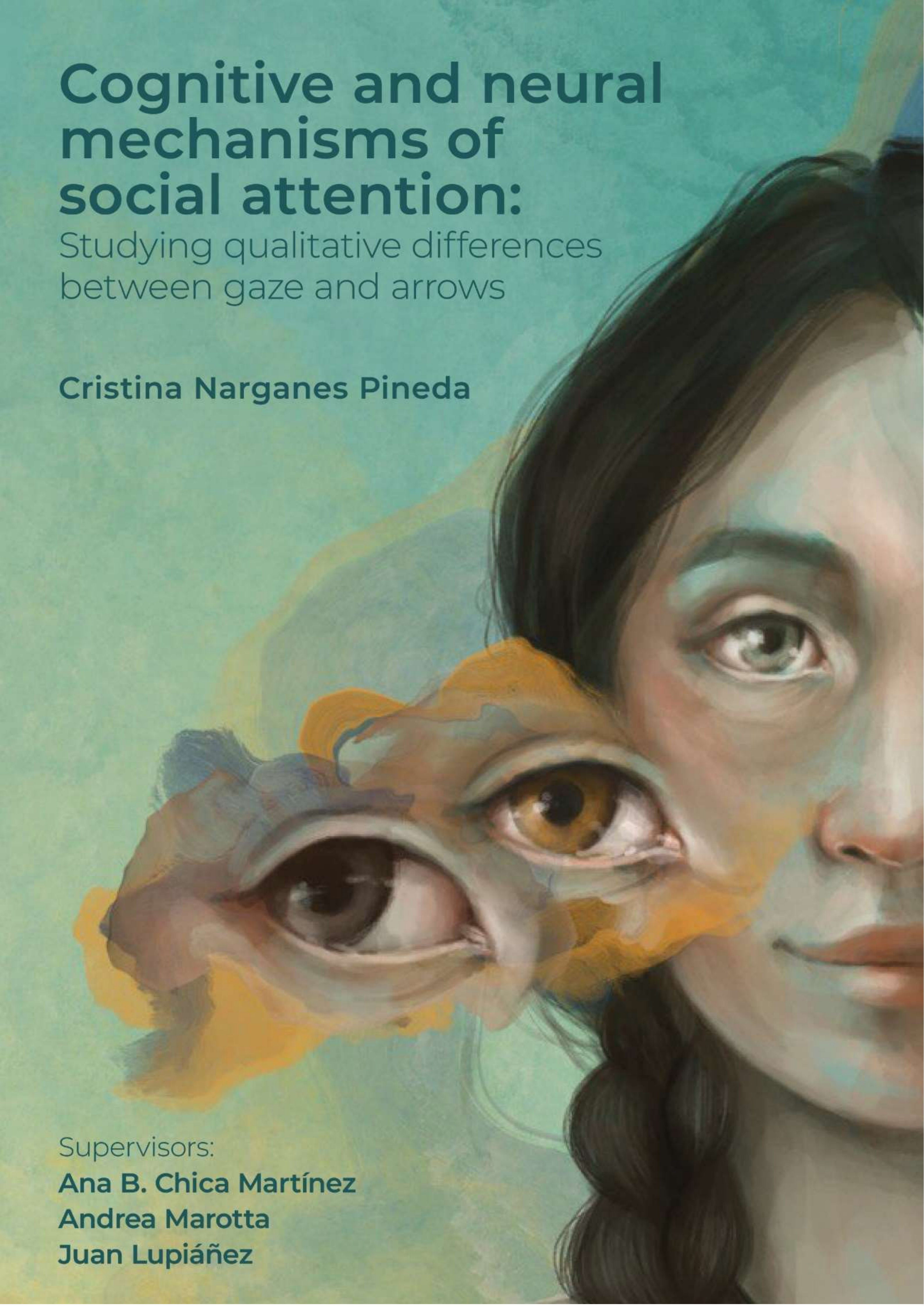

Cognitive and neural mechanisms of social attention:

Studying qualitative differences between gaze and arrows

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DOCTORAL THESIS

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Cognitive and neural mechanisms of social attention: studying qualitative differences between gaze and arrows

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A mi madre y a mi padre

A mis hermanas

A Oliver, compañero incansable

Y al amor, por ser siempre motor

"Defiende tu derecho a pensar, porque incluso pensar de forma errónea es mejor que no pensar"

Hypatia de Alejandría

The front page and back page of this doctoral thesis have been designed and drawn by Klara Hemmerich.

La portada y contraportada de esta tesis doctoral ha sido diseñada y realizada por Klara Hemmerich

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ABSTRACT

The ability of humans to perceive and process others' gaze direction has been crucial for their survival. Gaze has, on the one hand, a great social significance that triggers the initiation of interaction with others, and on the other hand, a special status as an attentional signal, which makes us change the direction of our attention to the same location where the other is paying attention to (Birmingham & Kingstone, 2009). This interest in knowing where other people are directing their attention is what we know as *Social Attention*.

Gaze processing requires the joint involvement of the neural mechanisms that underlie the so-called 'social brain', which includes temporo-occipital and prefrontal cortex regions. These regions participate in gaze processing together with parietal regions, reflecting the engagement of the attentional system to encode the spatial direction of the others' gaze and the orienting of attention in that direction (Hadders-Algra, 2022).

Gaze-triggered attention has been proposed to represent a unique attentional process reflecting the operation of a specialised cognitive and neural mechanism (S. Baron-Cohen, 1995). To assess this uniqueness, many studies have attempted to dissociate the attentional orienting triggered by gaze direction from that elicited by irrelevant and non-social stimuli, such as arrows, using variants of Posner's (1980) spatial orienting paradigm (Friesen & Kingstone, 1998). However, recent research shows that using such a paradigm, the attentional orientation generated by arrows and gaze is comparable, suggesting that both cues trigger the

same attentional orientation as the product of a domain-general orienting mechanism (Chacón-Candia, Román-Caballero, et al., 2023).

However, a different pattern of results emerges from other paradigms that seek to investigate the qualitative differences between the two cues by dissociating the attentional effects produced by the two stimuli. Recently, differences in the spatial congruency effects between arrows and gaze were observed using a spatial interference paradigm (Cañadas & Lupiáñez, 2012; Marotta et al., 2018a). These differences consist of standard congruency effects for arrow stimuli and reverse congruency effects (RCE) for gaze stimuli. The attentional mechanisms behind these differences in congruency effects have yet to be discovered.

The present thesis aims to study whether the attentional mechanisms elicited by eye-gaze differ from those engaged by just symbolic non-social stimuli, such as arrows. Specifically, we sought to understand the cognitive and neural mechanisms that would underlie the differences observed in the spatial congruency effect between the two stimuli. Three studies were carried out to answer this objective, using different variants of the spatial interference paradigm, together with an extensive review of the field of study.

In the first study, we sought to determine the nature of the attentional processes behind the standard congruency effects found with arrows and the RCE found with gaze stimuli. To this end, we examined whether the sequential congruency effects triggered by arrows and gaze could be generalised from one stimulus to another, using an intrablock task design, in which stimulus type was manipulated on a trial-by-trial basis. Results showed standard and reversed sequential congruency effects for the arrow and gaze stimuli, respectively, when presenting successive trials of the same stimulus. Furthermore, when presenting alternating stimuli, it was observed that the sequential congruency effects could be generalised across stimuli, regardless of the type of preceding stimulus. These results were replicated even when using other non-social stimuli, such as words indicating a direction and presenting whole faces, rather than eyes. These findings supported the co-existence of a shared spatial interference component between the arrow and gaze stimuli, which generalises sequential congruency effects between the two stimuli. The results also suggest the existence of an additional, possibly social, component involved only in the processing of gaze stimuli, which would produce the RCE.

In the second study of this thesis, the eye contact hypothesis was tested as responsible for the gaze-specific mechanism that produces the reversal in congruency. For this purpose, we used an implicit task (where participants responded to the colour of the stimuli) and an explicit task (where participants responded to the direction of the stimuli). Whereas in the explicit task, opposite congruency effects were observed between the two stimuli, in the implicit task no congruency effects are observed, neither for arrows nor for gaze. This suggested that the eye contact hypothesis is not the most appropriate hypothesis to explain the RCE observed with gaze (as eye contact still occurred in the implicit task where the RCE was not observed). The same pattern of results was replicated when replacing the manual response with a verbal one, suggesting that response-related motor priming components would not be involved in congruency effects.

In the third experiment, a functional magnetic resonance imaging (fMRI) design was used to explore the neural substrates involved in the attentional processes behind the standard congruency effects found with arrows and the RCE found with gaze stimuli. Shared neural mechanisms between arrow and gaze stimuli were observed in the functional connectivity between regions of the ventral attentional network and temporo-occipital regions. In addition, dissociable neural mechanisms were observed between both stimuli: 1) the functional connectivity between the right FEF and regions of the occipital cortex: this functional coupling was increased for congruent as compared to incongruent stimuli, and this result was larger for gaze than arrow stimuli. 2) The functional connectivity between the right FEF and regions of the left frontoparietal cortex was increased for incongruent as compared to congruent trials, and this result was only observed for arrows but not for gaze. These findings revealed shared neural networks between the two stimuli associated with spatial resolution and attentional orientation, as well as an additional set of regions that were differentially involved in the processing of each stimulus.

Taken together, the results of the three studies indicate shared attentional and neural mechanisms between both stimuli, responsible for the standard spatial congruency effects that we propose contribute to the processing of both arrows and gaze. At the same time, a gaze-specific mechanism responsible for the RCE would coexist. This specific gaze mechanism is not related to the eye contact effect. Therefore, other hypotheses are proposed to explain the RCE that occurs with the gaze.

The present doctoral thesis provides new data to help us to understand the cognitive and neural processes underlying the observed qualitative differences between social and non-social stimuli. We expect that these findings will contribute research on *social attention.*

RESUMEN

La capacidad de los seres humanos para percibir y procesar la dirección de la mirada de los otros ha sido crucial para su supervivencia. La dirección de la mirada de otros tiene, por un lado, un gran significado social que provoca el inicio de una interacción y por otro, un estatus especial como señal atencional, que nos hace cambiar la dirección de nuestra atención a la misma localización donde la otra persona está atendiendo (Birmingham & Kingstone, 2009). Este interés por conocer hacia dónde dirigen su atención otras personas es lo que conocemos como *Atención Social*.

El procesamiento de la mirada requiere la participación conjunta de mecanismos neurales que están a la base del denominado “cerebro social”, que incluye regiones de la corteza temporo-occipital y la corteza prefrontal. Estas regiones participarían en el procesamiento de la mirada junto a regiones parietales, reflejando el compromiso del sistema atencional para codificar la dirección espacial de la mirada del otro, y orientar la atención en esa dirección (Hadders-Algra, 2022).

Se ha propuesto que la atención desencadenada por la mirada podría representar un proceso atencional único, que reflejara el funcionamiento de un mecanismo cognitivo y neural especializado (S. Baron-Cohen, 1995). Para evaluar esta singularidad, muchos estudios han intentado disociar entre la orientación atencional de la mirada y la orientación atencional de otros estímulos evolutivamente irrelevantes y no sociales, como las flechas, utilizando variantes del paradigma de orientación espacial de Posner (1980) (Friesen & Kingstone, 1998). Sin embargo, investigaciones recientes han demostrado que al utilizar este paradigma no se encuentran diferencias entre la orientación atencional generada por las flechas, y la orientación atencional generada por la mirada. Lo que sugiere

que ambas señales desencadenarían la misma orientación atencional, producto de un mecanismo de orientación atencional de dominio general (Chacón-Candia, Román-Caballero, et al., 2023).

Sin embargo, un patrón diferente de resultados emerge cuando se usan otros paradigmas que buscan investigar las diferencias cualitativas entre ambas señales, logrando disociar los efectos atencionales que producen ambos estímulos. Recientemente, usando un paradigma de interferencia espacial (Cañadas & Lupiáñez, 2012; Marotta et al., 2018a), se han observado diferencias en los efectos de congruencia espacial entre flechas y miradas. Estas diferencias consisten, en efectos de congruencia estándar para los estímulos de las flechas y efectos de congruencia revertida para los estímulos de la mirada. Los mecanismos atencionales que estan a la base de estas diferencias aún no se conocen.

Esta tesis tiene como objetivo estudiar los mecanismos atencionales producidos por estímulos sociales, como la mirada, y su diferenciación de los mecanismos atencionales producidos por estímulos no sociales, como las flechas. Específicamente, buscábamos entender los mecanismos cognitivos y neurales que estarían a la base de las diferencias observadas en los efectos de congruencia espacial entre ambos estímulos. Para responder a este objetivo, se llevaron a cabo tres estudios, utilizando diferentes variantes del paradigma de interferencia espacial, junto a una amplia revisión del campo de estudio.

En el primer estudio buscábamos determinar la naturaleza de los procesos atencionales que estaban detrás de los efectos de congruencia estándar encontrados con las flechas y de los efectos de congruencia revertida encontrados con los estímulos de la mirada. Para ello se examinó si los efectos secuenciales de congruencia desencadenados por flechas y miradas podrían generalizarse de un estímulo a otro, usando un diseño de la tarea intrabloque, en el que el tipo de estímulo se manipulaba ensayo a ensayo. Los resultados mostraron efectos secuenciales de congruencia estándar y revertida para los estímulos de flechas y miradas, respectivamente, al presentar ensayos sucesivos del mismo estímulo. Además, al presentar los estímulos alternados, se observó que los efectos secuenciales de congruencia podían generalizarse entre estímulos, independientemente del tipo de estímulo anterior. Estos resultados fueron replicados incluso al utilizar otros estímulos no sociales, como palabras que indicaban una dirección y presentando caras enteras, en vez de ojos. Estos hallazgos sugieren la co-existencia de un componente de interferencia espacial compartido entre los estímulos de flechas y miradas, el cual produce la generalización de los efectos secuenciales de congruencia entre ambos estímulos. Más un componente adicional, posiblemente social, implicado sólo en los estímulos de la mirada, que produciría los efectos revertidos de congruencia.

En el segundo estudio de esta tesis se testó la hipótesis del contacto ocular como responsable del mecanismo específico de la mirada que produce la reversión en la congruencia. Para este fin se utilizó una versión implícita de la tarea (donde los participantes respondían al color de los estímulos) y otra explícita (donde los participantes respondían a la dirección de los estímulos). Mientras que en la tarea explícita se observaron efectos de congruencia opuestos entre ambos estímulos, en la tarea implícita no se observaron efectos de congruencia. Estos datos sugirieron que la hipótesis de contacto ocular (Cañadas & Lupiáñez, 2012) no sería la más adecuada para explicar los efectos de congruencia revertida que se observan con la mirada (ya que en la tarea implícita seguía produciéndose contacto ocular, pero no se produjo el efecto de congruencia revertido en los estímulos de la mirada). El mismo patrón de resultados se replicó al sustituir la respuesta manual por una verbal, sugiriendo que componentes de preparación motora relacionados con la respuesta no estarían implicados en los efectos de congruencia.

En el tercer experimento se utilizó un diseño de resonancia magnética funcional (fMRI) para explorar los sustratos neurales implicados en los procesos atencionales que estarían a la base de los efectos de congruencia estándar, encontrados con las flechas y de los efectos de congruencia revertida, encontrados con los estímulos de la mirada. Se observaron mecanismos neurales compartidos entre los estímulos de flechas y miradas en la conectividad funcional entre regiones de la red de atención ventral y regiones temporo-occipitales. Además se observaron mecanismos neurales disociables entre ambos estímulos en: 1) la conectividad funcional entre el FEF derecho y regiones de la corteza occipital: la conectividad funcional aumentó para los estímulos congruentes en comparación con los incongruentes, y este resultado fue mayor para los estímulos de mirada que para los de flecha. 2) la conectividad funcional entre el FEF derecho y las regiones de la corteza frontoparietal izquierda aumentó para los ensayos incongruentes en comparación con los congruentes, y este resultado sólo se observó para las flechas pero no para la mirada. Estos hallazgos revelaron redes neurales compartidas entre ambos estímulos, asociadas con la resolución del conflicto espacial y la orientación atencional, así como un conjunto adicional de regiones que estaban implicadas de forma diferencial en el procesamiento de cada estímulo.

En conjunto, nuestros resultados indican que existen mecanismos atencionales y neurales compartidos entre ambos estímulos, responsables de los efectos de congruencia espacial estándar, que ocurrirían por igual entre flechas y miradas. Estos mecanismos compartidos estarían relacionados con componentes espaciales y direccionales presentes en ambos estímulos. Por otra parte, se propone la existencia de un mecanismo específico de la mirada, responsable de los efectos de congruencia revertida. Este mecanismo específico de la mirada no estaría relacionado con el efecto de contacto ocular. Por lo que se proponen otras hipótesis que expliquen el efecto de congruencia revertida, que ocurre con los estímulos de la mirada.

La presente tesis doctoral proporciona nuevos datos que nos ayudan a entender los procesos cognitivos y neurales que subyacen a las diferencias cualitativas observadas entre estímulos sociales y no sociales. Esperamos que estos hallazgos contribuyan a la investigación sobre *Atención Social.*

Prefacio

En octubre de 2015 llegué a Granada acompañada de mi padre. Aquel no sería, muy a su pesar, un viaje de turismo, sino más bien un viaje en el que haría de mi consejero, como en tantas otras ocasiones, en el inicio de una nueva etapa.

Aquella etapa empezó como lo hacen casi todas: buscando un nuevo hogar. Todo aquel que conoce Granada conoce también su fama universitaria y la cantidad de estudiantes que llegan cada año, así como la diversidad de pisos que ofrece. Pisos antiguos, al estilo *Cuéntame cómo pasó*, pisos modernos, pisos baratos, pisos caros, compañeros/as mayores, compañeros/as jóvenes…

Mi padre, una persona muy expresiva en su rostro, paseaba por aquellas casas examinando cada detalle y escuchando con atención a cada persona que nos enseñaba una habitación. Mi padre inspeccionaba las estancias y su atención se centraba en lo que, para él, eran los requisitos mínimos que debía tener un hogar. En aquellas visitas no nos daba tiempo a explorar todas las estancias o asimilar todos los estímulos a los que nos veíamos expuestos; sin embargo, aún recuerdo cómo su mirada guiaba la mía a cada lugar que él exploraba.

Primero su mirada directa llamaba mi atención e iniciaba así una interacción social conmigo a nivel no verbal. Movía sus ojos en una dirección, que yo seguía automáticamente y nos dirigíamos, por ejemplo, hacia las ventanas. Entonces me preguntaba: ¿Pero cierran bien?

Él seguía recorriendo visualmente estancias como la cocina, observando los electrodomésticos, los grifos, y los suelos guiado por sus expectativas, pensando cómo debían ser. Al mismo tiempo, su interés orientaba al mío para que atendiéramos a los mismos lugares, aquellos que para él eran importantes. De pronto, que el fregadero estuviera muy sucio o escuchar una música repentina muy alta, podían distraer nuestra atención. Pero incluso en estos momentos, en los que mi observación se centraba más en la música u en otros estímulos externos irrelevantes, él volvía a hacer contacto ocular conmigo para que atendiera a lo mismo que él.

Igual que mi padre, las personas que nos enseñaban el piso hablaban y movían sus ojos hacia los lugares y los estímulos que querían que nosotros también viéramos. En ocasiones intentaban no mover sus ojos hacia espacios sucios de los que, al mismo tiempo, se disculpaban y prometían que no eran siempre así.

Este pequeño relato, cargado de cotidianeidad, muestra lo que ocurre cuando la atención visual se inserta en el mundo social (Richardson et al., 2015), convirtiendo procesos de orientación espacial comunes en complejas interacciones sociales que incluyen la comunicación interpersonal, el contexto visual y la relación entre las personas que lo comparten.

El ejemplo, aunque sencillo, también muestra cómo la mirada de los otros tiene, por un lado, un gran significado social que provoca el posible inicio de una interacción con los otros y, por otro, un estatus especial como señal atencional, que nos hace cambiar la dirección de nuestra atención a la misma localización donde el otro está atendiendo para poder conocer el foco de atención, los intereses, las intenciones y los estados mentales de las otras personas (Birmingham y Kingstone, 2009; Baron-Cohen, 1995).

THEORETICAL AND EMPIRICAL INTRODUCTION

CAPÍTULO 1. De la atención visual a la atención social

1.1 Conceptos clave sobre la atención visual

Durante nuestro día a día estamos expuestos a una gran cantidad de información, una parte de ella la percibimos gracias a nuestro sistema visual. Esta información guía nuestro comportamiento, y está relacionada no sólo con la percepción del medio físico si no también con el procesamiento del medio social. Dado que la cantidad de información que somos capaces de procesar es limitada, debemos ser capaces de filtrar y seleccionar aquella información que sea más útil y adecuada en cada momento (Broadbent, 1958). La atención se convierte por lo tanto, en un mecanismo necesario y esencial, que controla y orienta nuestro comportamiento de acuerdo a un objetivo o meta determinada (Tudela, 1992). La atención tiene una función selectiva, dirigiendo nuestro comportamiento hacia estímulos que consideramos relevantes, e ignorando los estímulos que consideramos irrelevantes. Asimismo, la capacidad de orientar la atención en el espacio nos ayuda a mejorar el procesamiento de las ubicaciones atendidas.

La atención puede orientarse de forma abierta cuando los receptores, como la cabeza y los ojos se orientan hacia el estímulo relevante al que queremos atender, o de forma encubierta dirigiendo sólo la atención, sin que los receptores (ej. ojos) miren directamente hacia el estímulo atendido (Posner et al., 1978). Esto implica que ambos actos pueden disociarse, es decir, que la localización a la que alguien atiende, no tiene por qué ser la localización a la que esté mirando (Posner, 1980).

En general podemos seleccionar y atender a nuestro alrededor guiados por nuestros objetivos e intenciones de forma controlada bajo el control del procesamiento de “arriba-abajo”. Pero también podemos orientar nuestra atención por la saliencia o relevancia de un estímulo del entorno, bajo el control del procesamiento de "abajo-arriba" (Jonides, 1981).

De la misma forma, la atención puede orientarse de dos formas diferentes, por un lado de forma voluntaria o endógena en base a los objetivos, metas, expectativas e intenciones de la persona o tarea, por ejemplo cuando mi padre atendía y comprobaba si las ventanas cerraban o no. Y por otro lado, de forma involuntaria o exógena, guiada por las características propias de los estímulos; por ser inesperados o novedosos; por ejemplo mientras mi padre y yo inspeccionábamos la cocina, la música alta captó nuestra atención (Yantis & Jonides, 1990). Estas dos formas de orientación atencional han sido estudiadas en el laboratorio mediante el *Paradigma de Costes y Beneficios* (Chica et al., 2014; Posner, 1980). Este paradigma utiliza la atención encubierta para estudiar la orientación de la atención en el espacio. El paradigma consiste en presentar un punto de fijación en el centro de la pantalla, donde los participantes deben fijar la mirada. A continuación, a la derecha o izquierda de dicho punto de fijación se presenta una señal atencional que dirige la atención a una ubicación, donde posteriormente puede aparecer o no aparecer el estímulo objetivo al que hay que responder. Cuando los estímulos objetivos se presentan en el lugar indicado por la señal se genera un ensayo válido, mientras que si los estímulos objetivos se presentan en el lugar contrario al indicado por la señal, esto genera un ensayo inválido. Generalmente con este paradigma se obtiene un efecto atencional de facilitación en la orientación producido por la señal, el cual consiste en tiempos de reacción más rápidos para los ensayos válidos en comparación a los ensayos inválidos (Posner, 1980). En ocasiones se utilizan ensayos neutros, en los cuales la señal no indica dónde aparecerá el estímulo objetivo. Al incluir los ensayos neutros en el paradigma, los efectos atencionales consisten en una mejora en la ejecución de los ensayos válidos (con respecto a los ensayos neutros), denominada beneficio atencional, y un decremento en la ejecución de los ensayos inválidos (con respecto a los ensayos neutros), denominada coste atencional (Chica et al., 2014). En ocasiones, los ensayos neutros no se comportan tal y como se esperaría (pueden generar respuestas más rápidas que los ensayos válidos e inválidos, o respuestas más lentas que ambos tipos de ensayos), por lo que no siempre se utilizan (Chica et al., 2014; Riggio et al., 1998).

Para estudiar la orientación atencional endógena y exógena con el paradigma de costes y beneficios es necesario manipular la naturaleza y características de la señal. En el estudio de la atención endógena se utilizan señales centrales, por ejemplo una flecha apuntando o una cara mirando en alguna dirección, o una señal con color que indica dónde aparecerá el objetivo. Esta señal simbólica debe ser decodificada para poder orientar la atención a la localización indicada (Jonides, 1981; Remington & Pierce, 1984). Para que aparezcan los efectos atencionales es necesario que las señales centrales simbólicas sean predictivas (por ejemplo indicando la localización señalada o válida el 80% de las veces, y la no señalada o inválida el otro 20% de las veces) (Jonides, 1981; Posner, 1980).

En el estudio de la atención exógena se utilizan señales periféricas (por ejemplo, un cambio en la luminancia de la señal o la aparición de un estímulo nuevo que actúa como señal), que se presentan en una de las posibles localizaciones donde posteriormente puede aparecer el estímulo objetivo. Las señales exógenas o periféricas indican directamente una localización concreta, a la que la atención se orienta automáticamente, por lo que no es necesario que sean predictivas para poder orientar la atención en una dirección. Cuando se estudia la atención exógena, estas señales no son predictivas (50% ensayos válidos y 50% de ensayos inválidos). Sin embargo, en algunos estudios se ha manipulado la predictividad de estas señales, de manera que las señales captan la atención exógenamente debido a su saliencia, pudiendo la atención mantenerse en ese lugar (si aumenta la proporción de ensayos válidos) o desengancharse de ese lugar (si aumenta la proporción de ensayos inválidos) (Posner & Cohen, 1984).

Además, este paradigma permite variar el intervalo (SOA – *Stimulus Onset Asynchrony*) de tiempo entre la presentación de la señal (exógena o endógena) y la presentación del objetivo con el fin de estudiar el curso temporal de la orientación. Los beneficios atencionales (también conocidos como facilitación) aparecen, de forma general, sobre los 100-150 ms para las señales periféricas y para las señales centrales a los 300 ms. Sin embargo, mientras que el efecto atencional de las señales endógenas se mantiene en intervalos prolongados (1-2 seg.), el efecto atencional de las señales periféricas no predictivas es más transitorio y se invierte entre los 300-700ms (dependiendo del tipo de tarea) (Lupiáñez et al., 1997). Esta inversión consiste en tiempos de reacción más rápidos para los ensayos inválidos en comparación a los ensayos válidos en los SOAs largos, lo que se conoce como inhibición de retorno (IR) (Posner et al., 1985). Este efecto se ha interpretado como la inhibición del retorno de la atención a localizaciones previamente atendidas, lo que facilitaría la búsqueda visual en localizaciones que no han sido exploradas previamente (Klein, 2000; Lupiáñez et al., 2006).

Numerosos estudios han tratado de desentrañar el funcionamiento de estas dos formas de orientación atencional (endógena y exógena), así como la posible interacción entre ambas (Berger et al., 2005; Chica et al., 2013; Yantis & Jonides, 1990). Estudios posteriores han investigado la predictibilidad de las señales centrales y periféricas, así como las distinciones en el carácter automático o más controlado de las señales utilizadas. De hecho, aunque la dirección de la flecha es un estímulo ampliamente utilizado como señal endógena, se considera que puede actuar como señal exógena, y orientar la atención de forma automática al estar los seres humanos muy familiarizados con su significado simbólico (Hommel et al., 2001; Ristic et al., 2002). De la misma forma se ha demostrado que una cara con una mirada como señal central no predictiva, actúa (en algunos aspectos) como una señal exógena produciendo cambios automáticos de la atención a los lugares señalados (Friesen & Kingstone, 1998), seguramente debido a la importancia evolutiva que ha tenido atender y seguir la mirada de los otros (Birmingham & Kingstone, 2009). Generalmente, los estudios que han utilizado estos estímulos como señales atencionales muestran resultados mixtos sobre las modulaciones de ambas señales en la orientación espacial endógena y exógena (Berger et al., 2005; Birmingham & Kingstone, 2009; Hommel et al., 2001; Ristic et al., 2002). Este tema será ampliamente discutido en el capítulo 2.

1.2 ¿Qué es la atención social?

La *atención social* es un término que ha sido ampliamente utilizado en las últimas décadas dentro de la literatura de neurociencia social y cognición social, debido al creciente interés en los procesos cognitivos implicados en las interacciones sociales (Birmingham & Kingstone, 2009; Capozzi & Ristic, 2018; Gobel et al., 2015; Hessels, 2020; Schilbach, 2015) . Se considera un constructo conceptual caracterizado por un conjunto de procesos cognitivos que aparecen cuando estamos ante la presencia de otros. De acuerdo con Salley y Colombo, (2016) abarcaría no sólo la simple atención al mundo social, que implicaría un proceso de percepción (atención visual social) si no también, el grado de atención y compromiso con los estímulos sociales (motivación social), así como el comportamiento social debido a las interacciones con nuestros congéneres, para lo que es necesario una evaluación e interpretación de los estímulos y del mundo social (Capozzi & Ristic, 2018).

Durante esta tesis utilizaremos el concepto en su definición más elemental, como el proceso cognitivo que estaría a la base del interés que tiene el ser humano por saber hacia dónde dirigen su atención otras personas y los cambios en la orientación atencional que eso desencadena (Birmingham & Kingstone, 2009). La capacidad para dirigir nuestra atención hacia donde otros dirigen la suya ha sido y es una habilidad crucial para nuestra supervivencia, permitiéndonos identificar el peligro y las recompensas del entorno. Hoy en día, estar atento a dónde atienden los demás, y en especial hacia dónde dirigen su mirada, nos permite interactuar con nuestro entorno y con el resto de personas, creando interacciones sociales exitosas (Capozzi & Ristic, 2018; Gobel et al., 2015; Risko et al., 2016).

Sin embargo, la mirada no es la única señal atencional que puede indicarnos el foco de atención de la otra persona; otras características de la cara, la orientación de la cabeza, señalar con los dedos, así como la posición y movimiento del cuerpo han sido consideradas señales sociales que nos orientan en mayor o menor medida. El uso automático de una señal u otra radica en si las señales están disponibles para el procesamiento o no. Si todas las señales están disponibles entonces existe una jerarquía en la que los ojos proporcionan una señal más valiosa que la orientación de la cabeza y el cuerpo (Emery, 2000).

1.2.1 La importancia de la mirada en el desarrollo filogenético

Cuando percibimos una escena compleja y abarrotada de estímulos, los rostros humanos son los primeros en capturar nuestra atención y ser procesados, ya que transmiten información social relevante, como la identidad, el género, la edad o las emociones (Langton et al., 2008; Oruc et al., 2019; Simion & Di Giorgio, 2015). De hecho, contamos con una red neural especializada en el procesamiento de rostros (Bernstein & Yovel, 2015; Haxby et al., 2000). Varios estudios sugieren que los recién nacidos tienen una predisposición para prestar atención a los rostros y a otros estímulos similares (Farroni et al., 2005; Frank et al., 2009; Johnson et al., 1991; Simion & Di Giorgio, 2015). Entre los 3 y los 9 meses de edad, los bebés enfocan gradualmente su atención a los rostros, desarrollando la capacidad de atender y responder a ellos a medida que crecen (Frank et al., 2009). Además, durante el primer año de vida comienzan a reconocer identidades (Pascalis et al., 1998), reconocen y muestran preferencias por rostros de su misma raza (Kelly et al., 2007), pueden percibir emociones (Palama et al., 2018) y seguir la dirección de la mirada de los demás (Butterworth & Jarrett, 1991; Farroni et al., 2002).

Diversas investigaciones (Gliga & Csibra, 2007; Johnson et al., 2015) ponen de manifiesto cómo los seres humanos tendemos a mirar la región facial de los ojos más que a otras regiones de la cara por la cantidad de información social que nos aporta. Las personas son realmente muy sensibles a la dirección de la mirada de los demás. La mirada tiene una doble función, por un lado, al prestar atención a los ojos de los otros podemos descubrir hacia dónde miran e inferir lo que la persona está pensando. Por otro lado, nuestros ojos podrían orientar la atención de otra persona en una dirección determinada (Friesen & Kingstone, 1998; Gobel et al., 2015)

Incluso cuando las caras se presentan de forma aislada, sin contexto, los ojos son el rasgo facial más atendido (Itier et al., 2007).

La importancia de la mirada radica incluso en cómo ha evolucionado la morfología de los ojos humanos, ya que aporta información sobre hacia dónde los dirigimos. Los ojos humanos se diferencian de los de otras especies en el tamaño y color de la esclerótica (zona blanca que rodea a la pupila), visiblemente más grande que en otros animales, lo que ha facilitado la detección de la pupila y su movimiento (Emery, 2000; Kobayashi & Kohshima, 1997). Las hipótesis evolutivas afirman que los ojos humanos evolucionaron por la necesidad de comunicar estados emocionales y mentales, así como información sobre el entorno (Kobayashi & Kohshima, 1997).

La capacidad de percibir, procesar e interpretar las miradas es un requisito indispensable en el desarrollo de diversas habilidades comunicativas, relacionadas con la atención conjunta y la teoría de la mente (Macrae et al., 2002; Tomasello, 1995).

1.2.2 Las diferentes direcciones de la mirada y sus significados

Una mirada que se dirige hacia nosotros capta nuestra atención rápidamente modulando nuestro comportamiento (Senju & Hasegawa, 2005), debido a que suele ser el inicio de una interacción social. Baron-Cohen, (1995) sugirió que existe en el cerebro un detector de la dirección de la mirada encargado de identificar si somos el objeto de atención de la otra persona, o si por el contrario, la persona está mirando en otra dirección. Este módulo sería imprescindible para desencadenar procesos de mentalización y teoría de la mente, haciendo posible interpretar los estados mentales de la otra persona (Cañigueral & Hamilton, 2019). Este efecto de mirada directa o mirada mutua, donde la atención de dos individuos se dirige mutuamente el uno al otro (Emery, 2000) se denomina también efecto de contacto ocular. Cuando se percibe el contacto ocular, éste modula el procesamiento cognitivo y la respuesta conductual posterior, ya que provoca una mejor asignación de los recursos atencionales, aumentando el sistema de arousal (Conty et al., 2007; Senju & Johnson, 2009)(**Fig. 1.A**).

En general la mirada directa atrae la atención y se detecta más rápido que una mirada desviada en tareas de búsqueda visual en el laboratorio (Conty et al., 2006; Macrae et al., 2002), pero también en la vida cotidiana entre una multitud (Crehan & Althoff, 2021). De hecho, la mirada directa nos distrae más que la mirada desviada si intentamos detectar estímulos periféricos (Senju & Hasegawa, 2005) o realizar una tarea mientras la mirada directa de una persona hace contacto visual con nosotros (Conty et al., 2010). La mirada directa o el contacto visual facilitan los juicios sobre diferentes aspectos de los ojos o las caras. Según la literatura, la mirada directa (en comparación con la mirada desviada) mejora la orientación atencional hacia los rostros (Mares et al., 2016), la discriminación de las emociones (Adams & Kleck, 2005; Hamilton, 2016; Hietanen et al., 2008; McCrackin & Itier, 2019; Milders et al., 2011) y la memoria de rostros (Conty & Grèzes, 2012). Además, la mirada directa o contacto ocular facilitan la categorización social de los rostros, ya sea según la raza, la identidad o el género, en comparación a cuando la mirada está desviada (Kloth et al., 2015; Macrae et al., 2002; McCrackin & Itier, 2019; Richeson et al., 2008). Por otro lado, varios autores postulan que el procesamiento del contacto ocular puede ocurrir automáticamente, incluso fuera de la conciencia. Estudios recientes en esta línea observan cómo cuando los rostros se presentan por debajo del umbral de la consciencia, la mirada directa o el contacto ocular desencadena procesos atencionales automáticos (Sato et al., 2007, 2016; Stein et al., 2011; Xu et al., 2018).

Otros estudios han mostrado que el contacto ocular no sólo puede facilitar la discriminación de características intrínsecas del rostro sino que puede afectar a un procesamiento social más complejo, acelerando las respuestas en una tarea de discriminación de color (Hietanen et al., 2016), aumentar los juicios sociales positivos sobre un rostro y una persona (Ewing et al., 2010) e incluso desencadenar procesos autoreferenciales (Hietanen & Hietanen, 2017). Estos resultados podrían apoyar la idea de que la demanda y el contexto de la tarea, consideradas influencias del procesamiento de "arriba-abajo", podrían modular el procesamiento de la mirada directa o el contacto ocular, y con ello la respuesta conductual posterior (Burra et al., 2019; Hamilton, 2016).

Si la mirada directa o el contacto ocular nos indica que somos nosotros el foco de atención, y se considera una señal no verbal para el inicio de una interacción social (Senju & Johnson, 2009), la mirada desviada o evitada (**Fig. 1.A**), hace referencia a una persona que aparta la mirada de nuestros ojos para mirar a otro lugar, lo que provoca que desplacemos automáticamente nuestra atención hacia donde la otra persona está mirando (Emery, 2000). El seguimiento de la mirada es uno de los procesos cognitivos clave, que permite a las personas aprender a través de la observación de la mirada de los otros (Frith & Frith, 2007; Shepherd, 2010). Nuestros congéneres pueden estar observando una ubicación u objeto relevante, que también sea importante para nosotros. Por lo que es útil, necesario e incluso inevitable, que nosotros movamos nuestros ojos y nuestra atención en la misma dirección, y hacia las mismas ubicaciones u objetos. El seguimiento de la mirada

(**Fig. 1.B**) se ha considerado un acto rápido y automático (Driver et al., 1999), que incluso, aparece en los recién nacidos de forma espontánea (Farroni et al., 2002; Hood et al., 1998). Siendo una de las primeras habilidades sociales de interacción que se desarrollan en la infancia (entorno al primer año de vida) (Moore, 2008). Diversos estudios muestran que los bebés podrían seguir la mirada de los otros, entorno a los 6-8 meses (Butterworth & Jarrett, 1991; Gredebäck et al., 2008), pudiendo incluso empezar a desarrollarse antes (Astor & Gredebäck, 2019). No obstante, el seguimiento de la mirada aunque puede ser un proceso que se inicia pronto, continúa desarrollándose durante los primeros años de vida, haciéndose cada vez más eficiente. Por ejemplo, al principio los bebes pueden detectar la mirada e intentar seguir su dirección, pero lo hacen basándose en la dirección de la cabeza y no en la de los ojos, posteriormente pueden seguir la dirección de los ojos de otros, pero no detectan lo mirado con precisión, no sería hasta los 12 o 18 meses que pueden seguir la mirada y buscar lo que los otros están mirando (Butterworth & Jarrett, 1991; Gredebäck et al., 2008; Moore, 2008). Por otra parte, el seguimiento de la mirada no sólo representa un proceso automático, si no también se ve influenciado por procesos controlados por el procesamiento de “arriba-abajo”, por ejemplo por juicios sobre lo que otros pueden estar mirando (Burra et al., 2019; Capozzi & Ristic, 2020; Frischen, Bayliss, et al., 2007).

Este acto de seguir la mirada del otro, hacia donde éste está atendiendo es el primer paso para establecer lo que denominamos como atención conjunta (Mundy & Newell, 2007). Cuando nos damos cuenta de que la otra persona está mirando un objeto específico reorientamos nuestra atención y ojos hacia esa dirección para mirar a la vez al mismo objeto (Emery, 2000) (**Fig. 1.C**). Esta capacidad surge en torno a los 6-8 meses con procesos como el seguimiento de la mirada y se desarrollaría hasta los 3 o 4 años (Mundy et al., 2007; Tomasello, 1995) considerándose un hito importante en el desarrollo social de los niños/as, por su participación en el desarrollo no sólo de otras habilidades sociales sino también de habilidades comunicativas (Mundy et al., 2003). Existen numerosos estudios sobre los procesos cognitivos y neurales de la atención conjunta y sus implicaciones en la cognición social (para revisiones más específicas ver Mundy, 2018 y para un debate sobre la naturaleza de la atención conjunta ver Siposova & Carpenter, 2019).

Siguiendo a Emery, 2000 si ambos individuos son conscientes de que están mirando el mismo objeto a la vez, entonces estaríamos un paso más allá a nivel social, en lo que denominaríamos atención compartida (**Fig. 1.D**). Aunque la diferencia con la atención conjunta es sutil, en este punto es necesario aclarar que ambas personas han llegado a prestar atención a ese objeto de forma diferente, por lo que sería lógico pensar que las atribuciones mentales que hacemos acerca del objeto y la otra persona serán diferentes para cada uno (ver Stephenson et al., 2021). La otra persona ha iniciado y liderado un acto de atención conjunta mientras que nosotros sólo habremos sido un seguidor (Bayliss & Tipper, 2006; Mundy & Newell, 2007; Stephenson et al., 2021). Tanto el acto de atención conjunta como la atención compartida son requisitos indispensables para el desarrollo del aprendizaje, la adquisición del lenguaje y la adquisición de competencias sociales relacionadas con la cognición social, como la teoría de la mente (**Fig. 1.E**) (Conty et al., 2007; Hessels, 2020). La teoría de la mente se describe como la habilidad para representar los estados mentales de la otra persona, en otras palabras, pensar sobre lo que otros pueden estar pensando (Quesque & Rossetti, 2020), por lo que se considera un proceso cognitivo de orden superior que, de acuerdo a Emery (2000), podría surgir de la combinación de todos los procesos descritos anteriormente (**Fig. 1. A-D**), junto a otros procesos cognitivos de orden superior, como la empatía o el sentido de agencia.

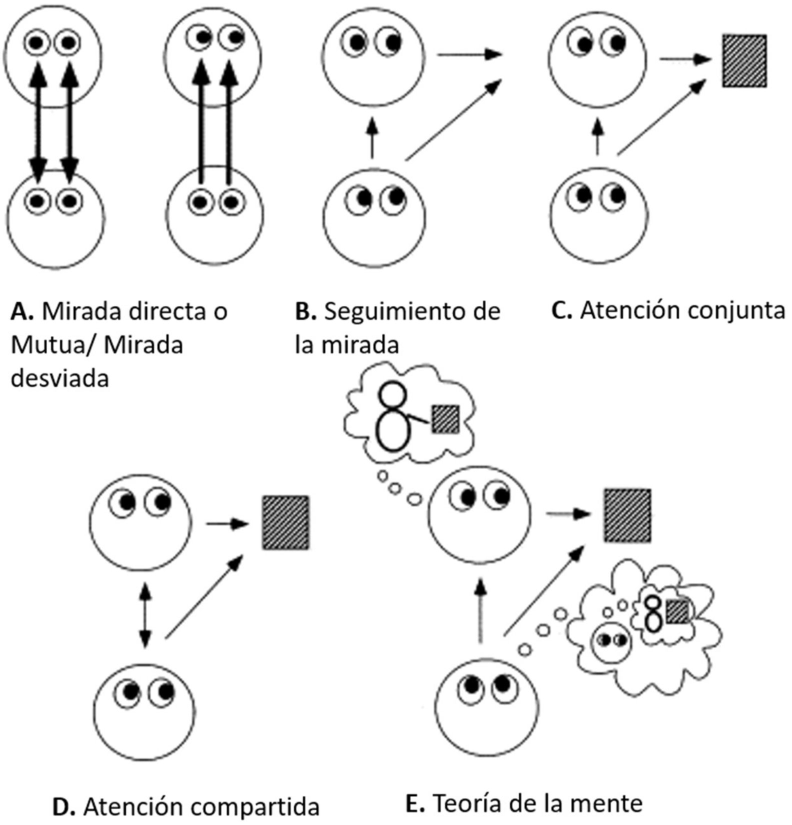

Figura 1. Representación pictórica de la dirección de la mirada como señal social y su evolución dentro de un contexto social. **A)** Mirada directa o mutua/mirada desviada. **B)** Seguimiento de la mirada. **C)** Atención conjunta. **D)** Atención compartida. **E)** Teoría de la mente. Adaptación de Emery (2000) con permiso de Elsevier Publishers.

Todos estos hallazgos han sido la base para que varios grupos de investigación propusieran que la atención a la mirada puede representar un proceso atencional único y reflejar el funcionamiento de un mecanismo cognitivo especializado (Farroni et al., 2002). Sin embargo, es necesario estudiar de qué forma atendemos a ella y bajo qué condiciones podría desencadenar procesos cognitivos y atencionales únicos, para considerarla un estímulo especial. Además, es importante dilucidar qué características o procesos podría compartir con otras señales atencionales que también son capaces guiar nuestra atención y orientarnos en el espacio. Durante esta tesis asumimos que, en base a la literatura descrita en este capítulo, la mirada es un estímulo especial que no sólo nos orienta hacia una dirección, si no que nos aporta mucha información social y no social, tanto de forma automática en base a un procesamiento de “abajo-arriba”, como desde un procesamiento más controlado de “arriba-abajo”. Los paradigmas en los que la mirada ha sido estudiada dentro de la atención social podrían ser clave para poder investigar todo su significado.

CAPÍTULO 2. ¿Cómo estudiar la atención social?

2.1 Aproximación cuantitativa para estudiar la atención social

2.1.1 El paradigma de Gaze-Cueing: las bondades de la mirada como señal atencional

Durante nuestro día a día seguimos la mirada de los otros y tendemos a atender a los mismos lugares y estímulos que los otros están atendiendo. Esta capacidad, tan común y cotidiana, ha sido crucial para el desarrollo de la cognición social. Los experimentos dentro del laboratorio han demostrado que la dirección de la mirada es una señal atencional especial, que genera cambios automáticos de nuestro foco atencional hacia donde otros están mirando (Driver et al., 1999; Friesen & Kingstone, 1998; Frischen, Bayliss, et al., 2007). Para estudiar su posible singularidad, varios estudios han utilizado una adaptación del *paradigma de Costes y Beneficios* (Chica et al., 2014; Posner, 1980), descrito anteriormente (capítulo 1). Esta adaptación de Friesen y Kingstone, (1998) ha servido para estudiar la orientación atencional producida por la mirada y con ello la atención social. La adaptación del paradigma, conocido como *Gaze-Cueing* (**Figura 2**)*,* consiste en presentar en el punto de fijación central una cara (real o esquemática) que actúa como señal atencional, al principio la cara mira al frente para posteriormente desviar la mirada hacia la derecha o la izquierda, señalando a una u otra ubicación. A continuación, tras un intervalo de tiempo variable (SOA) se presenta el estímulo objetivo que puede aparecer o no en la ubicación señalada previamente. En función del tipo de tarea, el estímulo objetivo, al que hay que dar respuesta, debe ser detectado, discriminado o localizado. Al igual que en el paradigma original de orientación espacial de Posner (1980), la tarea genera ensayos señalados o válidos, donde el estímulo objetivo aparece en la ubicación mirada por la cara; y ensayos no señalados o inválidos, donde el estímulo objetivo aparece en la ubicación opuesta a la mirada por la cara. Además, en este experimento, se eliminó la predictibilidad de la señal central, haciendo que la mirada no predijera la ubicación donde parecería el estímulo objetivo. De acuerdo al paradigma clásico y las manipulaciones realizadas con señales centrales simbólicas, ya que la señal de la mirada estaba ubicada en el centro y no era predictiva, se esperaba que ésta no produjera cambios en la orientación atencional, ya que una señal central simbólica y direccional sólo produce cambios en la orientación atencional si es capaz de predecir de forma fiable la ubicación del estímulo objetivo (Birmingham & Kingstone, 2009).

Sin embargo, la mirada central no predictiva provocó cambios en la orientación de la atención, al mostrar diferencias en el rendimiento entre los ensayos válidos e inválidos, generando el conocido efecto de *gaze-cueing*. Los participantes fueron más rápidos detectando el estímulo objetivo que aparecía en la ubicación previamente señalada (mirada por la cara) en comparación a cuando aparecía en la ubicación no señalada o no mirada, a pesar de que la señal de la mirada no predecía el lugar de aparición del objetivo y que las personas participantes habían sido instruidas para ignorar la mirada (S. Langton & Bruce, 1999). Este efecto atencional ocurría incluso si se usaban señales de miradas contrapredictivas, con las que era más probable que el objetivo apareciera en las ubicaciones no señaladas o no miradas (Driver et al., 1999; Jason Tipples, 2008). El efecto de *gaze-cueing*, puso de relieve cómo el cambio atencional provocado por la mirada es automático, al surgir rápidamente y en respuesta a una mirada central no predictiva (Birmingham & Kingstone, 2009; Capozzi & Ristic, 2018; Driver et al., 1999; Frischen, Bayliss, et al., 2007).

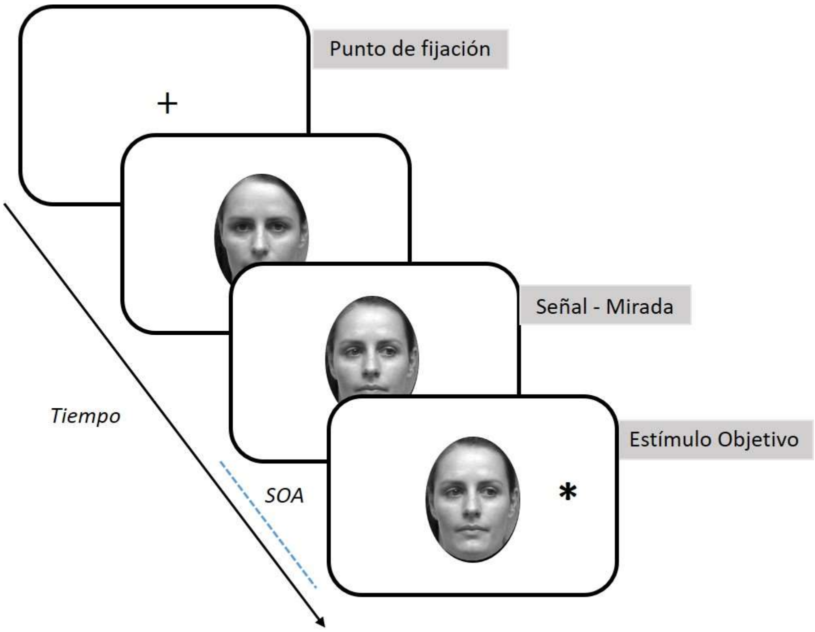

Figura 2. Representación del procedimiento del *paradigma de Gaze-Cueing.* Se muestra el ejemplo de un ensayo válido.

Al igual que en el efecto orientación general, al variar el intervalo de tiempo (SOA) entre la presentación de la señal (mirada desviada) y la presentación del objetivo podemos estudiar el curso temporal del efecto de *gaze-cueing*. Dado que el curso temporal de la atención endógena y exógena es claramente diferente (ver apartado 1.1), explorar el curso temporal de la orientación a la mirada ayuda a entender si este proceso tiene características similares a la orientación endógena o exógena (Frischen, Bayliss, et al., 2007; Nagata et al., 2012). Los estudios han demostrado que la mirada desviada usada como señal central orienta la atención rápidamente (en tan solo 14 ms tras el inicio de la señal en los estudios de Hietanen y Leppänen (2003) y en <200 ms en otros estudios, (Mckay et al., 2021). Asimismo, parece que el efecto de *gaze-cueing* puede mantenerse con la misma magnitud en

SOAs de 800 ms (Mckay et al., 2021), para luego reducirse en SOAs >1s (Frischen, Smilek, et al., 2007) o incluso revertirse para convertirse en inhibición de retorno (IR) (Frischen & Tipper, 2004). Las señales de la mirada central no predictiva producen un efecto de inhibición de retorno (IR) en SOAs largos (ej. >2s), con tiempos de reacción más rápidos en las ubicaciones no miradas o no señaladas en comparación a las miradas o señaladas (Frischen, Smilek, et al., 2007; Frischen & Tipper, 2004). Por lo tanto, la mirada central no predictiva produciría un efecto de inhibición de retorno (IR) diferente al producido por otras señales periféricas no predictivas. De hecho la inhibición de retorno con la mirada como señal parece no producirse hasta los 9 años (Jingling et al., 2015), mientras que los bebés ya suelen mostrar inhibición de retorno con señales periféricas (Clohessy et al., 1991). Estos estudios sugieren que la orientación de la atención guiada por las señales de la mirada tendría un curso temporal parcialmente diferente a la orientación de la atención guiada por otras señales periféricas (Mckay et al., 2021). Por otro lado, también se ha demostrado que la orientación a la mirada ocurre incluso a nivel preconsciente (Bailey et al., 2014; Sato et al., 2007), lo que podría apoyar la naturaleza exógena del efecto.

En algunas versiones del paradigma de *gaze-cueing* nos encontramos con modificaciones del paradigma, que es importante tener en cuenta. Frecuentemente se presenta una mirada directa antes de la mirada desviada, que actúa como señal (Bayliss & Tipper, 2006; Cui et al., 2014). Como hemos visto en el apartado 1.2, la mirada directa se considera una poderosa señal social capaz de modular y potenciar procesos de percepción y/o cognición social (Doi & Shinohara, 2013; Hietanen et al., 2018), por lo que sería razonable pensar que presentar o no presentar una mirada directa podría influir en los resultados en la tarea de *gaze-cueing*. Sin embargo, los resultados encontrados son heterogéneos, algunos autores (Heimler et al., 2015; Hietanen & Leppänen, 2003) no han encontrado diferencias en la magnitud del efecto de *gaze-cueing*, al presentar una mirada directa antes de la mirada desviada. Mientras que otros autores como Kompatsiari et al. (2018) muestran efectos de *gaze cueing* sólo cuando se presenta una mirada directa o contacto ocular previo. Por otro lado, los resultados de Dalmaso y colaboradores (2020a) muestran que el contacto ocular previo a la orientación de la atención afecta tanto a la programación de los movimientos oculares como a los mecanismos de seguimiento de la mirada en tareas de *gaze-cueing* de atención abierta, sólo cuando el contacto ocular sobresale dentro del contexto de la tarea. De igual manera, Breil et al. (2022), concluye que si bien una mirada directa previa a la tarea capta la atención, su influencia varía en función del contexto tanto facial como social en el que se presenta.

Un meta-análisis reciente (Mckay et al., 2021) sobre la magnitud del efecto de *gaze-cueing* y las variables que pueden modularlo, respalda los hallazgos sobre el hecho de que el contacto ocular o una mirada directa previa a la señal podría mejorar el efecto de señalización de la mirada, lo que apoya los efectos del contacto ocular descritos por Senju y Johnson, (2009). Además, se explora si las demandas del tipo de tarea (detección, localización o categorización) podrían modular la magnitud del efecto de orientación atencional que genera la mirada (efecto de *gaze-cueing*), obteniendo resultados heterogéneos. Los resultados sugieren que el efecto de *gaze-cueing* fue mayor en las tareas de localización en comparación a las tareas de detección (tareas menos demandantes). Mientras que el efecto de *gaze-cueing* fue menor en tarea de categorización (tareas más demandantes) en comparación a las tareas de detección (Mckay et al., 2021). En otro estudio metanalítico, los autores concluyen que el efecto de *gaze-cueing* aumenta con las demandas de la tarea, siendo más grande su magnitud en tareas de localización y discriminación que en las tareas de detección (Chacón-Candia, Román-Caballero, et al., 2023) Por otro lado, el tipo de señal utilizada (cara esquemática, cara de un avatar o artificial creada por ordenador, o una cara real de una fotografía) no modula el efecto de *gaze-cueing*. De hecho, Mckay y colaboradores (2021) aportan pruebas sólidas de que el efecto de *gaze-cueing* es equivalente cuando se usan estos tipos de caras, independientemente de que sean simples, complejas, reales o más ecológicas.

La expresión emocional de la cara que se presenta, como señal atencional, también ha mostrado modulaciones en el efecto de *gaze-cueing* (Bayliss et al., 2010). Dado nuestro interés y predisposición por entender los estados internos de los demás, no es de extrañar que una cara con una expresión emocional sea más atendida que una cara con una expresión neutra. Aunque, los resultados acerca de cómo las señales de caras emocionales modulan al efecto de *gaze-cueing* han sido dispares (ver Dalmaso et al., 2020b para una revisión más exhaustiva), análisis recientes muestran mejoras en la orientación de la mirada (efecto de *gaze-cueing*) cuando se presentan caras reales y cuando las caras reales muestran emociones de miedo en comparación a cuando muestran emociones de felicidad, asco o enfado (Mckay et al., 2021). En línea con la revisión de Dalmaso y colaboradores (2020b), existen varias características sociales asociadas tanto a las propias señales como al observador que podrían modular el efecto de *gaze-cueing*. Por ejemplo, procesos de cognición social considerados de alto nivel como asociar o inferir un estatus social alto a una determinada cara puede hacer que tendamos a seguir más su mirada que la de otra cara asociada a un estatus social bajo (Dalmaso et al., 2012).

En su conjunto estos hallazgos sugieren que la mirada como señal atencional es importante y especial, siendo capaz de dirigir nuestra atención hacia donde los otros están mirando de forma rápida, automática y permanente en el tiempo. La mirada como señal atencional parece tener una función adaptativa que guía y orienta nuestra atención de forma robusta, ya que aunque pueda verse influenciada por determinadas variables del entorno, el efecto de orientación atencional que desencadena (efecto de *gaze-cueing*) no desaparece fácilmente (Driver et al., 1999; Friesen & Kingstone, 1998; Frischen, Bayliss, et al., 2007; Mckay et al., 2021).

2.1.2 ¿Es la mirada una señal de orientación atencional única?

En contraste con los primeros estudios en los que se asumía que para orientar la atención las señales centrales, como la mirada o las flechas, debían predecir la ubicación del objetivo (Jonides, 1981), la literatura revisada en el apartado anterior sugiere que las señales de la mirada (incluso siendo una señal central no predictiva) desencadenan cambios automáticos de la atención hacia los lugares mirados. Sin embargo, la orientación de la atención guiada por las señales de la mirada tendría un curso temporal parcialmente diferente a la orientación de la atención guiada por otras señales periféricas (Mckay et al., 2021). Esto ha provocado que la mirada se considere como una señal única y especial, lo que se ha asociado a su naturaleza social innata y su significado biológico (ver capítulo 1).

No obstante, otros estudios han encontrado cambios automáticos de la atención cuando se han utilizado flechas como señales centrales no predictivas

(Friesen et al., 2004; Hommel, 2001; Ristic et al., 2002; Tipples, 2002). De hecho, el estudio de Hommel y colaboradores (2001) fue uno de los primeros en demostrar cómo una flecha no predictiva y una palabra direccional orientan la atención de forma automática, facilitando el procesamiento del estímulo objetivo posterior que aparece en las ubicaciones señaladas o nombradas previamente por las señales. Los autores concluyen que los símbolos (flechas y palabras) que nos comunican información espacial, y con los que tenemos mucha experiencia y aprendizaje desde edades tempranas, también son capaces de orientar nuestra atención de forma automática hacia ubicaciones señaladas, de manera muy similar a como lo hacen otros símbolos comunicativos sociales, como la mirada. Incluso en trabajos posteriores, se ha demostrado que utilizando señales de flecha contrapredictivas, donde era más probable que el objetivo apareciera en otro lugar diferente al señalado, la orientación atencional automática generada por flechas y miradas fue similar (Tipples, 2008). En relación a los datos anteriores, Kuhn & Benson (2007), mostraron que independientemente del tipo de señal, mirada o flecha, las latencias de los movimientos sacádicos fueron más rápidas para los ensayos válidos o señalados, en comparación a los ensayos neutros e inválidos o no señalados, mostrando efectos de facilitación comparables para ambas señales.

Estudios recientes apoyan las conclusiones de Hommel y colaboradores (2001), sugiriendo que una señal de flecha puede causar una orientación automática producto del aprendizaje de esta señal en nuestra vida y entorno cotidiano (Ristic & Kingstone, 2012). Esta idea estaría apoyada por estudios como los de Galfano et al., (2012) en los que testaron la resistencia a la supresión en la orientación atencional hacia señales de flechas y miradas. Ambas señales se presentaron antes del objetivo como distractores irrelevantes para la tarea. Los resultados demostraron que es difícil ignorar tanto las señales de la mirada, como las de las flechas.

A pesar de que se han llevado a cabo numerosos estudios para investigar las posibles diferencias en la orientación atencional desencadenada por las señales de flechas y miradas, los resultados no han mostrado diferencias o éstas han sido muy sutiles (Blair et al., 2017; Brignani et al., 2009; Galfano et al., 2012; Greene et al., 2009; Hayward & Ristic, 2013; Yokoyama et al., 2022). Una explicación plausible repetida a lo largo de la literatura es que, tanto la mirada como las flechas son señales atencionales importantes en nuestro día a día con las que tenemos mucha experiencia. Además, ambas comparten la capacidad de comunicar información direccional (Gibson & Kingstone, 2006)(Gibson & Kingstone, 2006), por lo que sería lógico pensar que ambas puedan orientar nuestra atención en el espacio de forma automática (Ristic & Kingstone, 2012).

En base a esta literatura, varios autores (Birmingham & Kingstone, 2009; Heyes, 2014; Santiesteban et al., 2014; Tipples, 2002; Wilson et al., 2017; Yokoyama et al., 2022) han propuesto que los efectos atencionales de la mirada son, al menos parcialmente, debidos a un proceso de orientación atencional de dominio general, que procesaría de la misma manera tanto la mirada como las flechas u otros estímulos no sociales, que indiquen una dirección en el espacio.

Recientemente, un exhaustivo meta-análisis (Chacón-Candia, Román-Caballero, et al., 2023) ha demostrado que no hay diferencias cuantitativas en la magnitud de los efectos de orientación atencional entre las señales de la mirada y las flechas, poniendo de relieve que tanto la mirada como las flechas producirían efectos de orientación atencional equivalentes, compartiendo procesos de orientación espacial y direccionalidad.

De acuerdo con autores, como Birmingham y Kingstone, (2009); Chacón-Candia, Román-Caballero, et al., 2023) es probable que el *paradigma de gaze-cueing* no sea el adecuado para captar las diferencias entre ambas señales. Es posible que las diferencias entre flechas y miradas estén presentes en cómo se orienta la atención dependiendo del tipo de señal (aproximación cualitativa) y no en cuánto se orienta (aproximación cuantitativa). Si esto es así, sería necesaria la adaptación o creación de paradigmas que sean capaces de estudiar la orientación espacial de dominio-general, que es probable que compartan ambas señales (flechas y miradas), así como los procesos que podrían ser diferentes entre ambas señales. Los procesos que pueden diferir entre ambas señales podrían estar relacionadas con las características sociales y atribuciones de mentalización inherentes a las señales de la mirada y que no podrían estar en las señales de flecha.

En línea con este punto de vista, algunos estudios han mostrado diferencias entre ambas señales cuando se utilizan variaciones del *paradigma de gaze-cueing* que potencian las cualidades sociales de la mirada, asignado a las señales de la mirada una intención o un proceso de mentalización, más allá de la mera orientación. Ejemplo de ello sería el estudio de Ristic & Kingstone, 2005 en el cual se utilizaba un paradigma de orientación con una señal ambigua, la cual podía percibirse como las ruedas de un coche o una cara con sombrero y ojos. Los resultados mostraron que si se les decía a las personas participantes que los estímulos eran ojos, se producía un efecto de orientación automática hacia las localizaciones miradas, difícil de disipar y que posteriormente permanecía aunque se les dijera que eran ruedas de coche. Por el contrario, si primero se les decía que eran ruedas de coche, el efecto de orientación automática no aparecía. De acuerdo a los autores, esto demuestra que un efecto de orientación social automático puede estar influenciado por el procesamiento de arriba-abajo (Ristic & Kingstone, 2005).

Otro ejemplo de esta idea, es el trabajo de Bayliss et al. (2006) que aunque recientemente, no ha podido ser replicado (Tipples & Pecchinenda, 2018), es interesante por la hipótesis y los datos que presenta. El experimento consistió en un paradigma de orientación con miradas y flechas como señales, en el que se presentaban objetos cotidianos como estímulos objetivos, que los pacientes debían categorizar ignorando la señal central. En el último bloque, después de categorizar los estímulos objetivos, se les pidió a los participantes que valoraran cuánto les gustaba cada uno de los estímulos objetivos presentados. Los resultados mostraron que los participantes preferían o les gustaban más los objetos mirados por las señales que los que no habían sido mirados. Cuando la señal fue una flecha este efecto desapareció, lo que demuestra que seguir la mirada de los otros y atender a lo mismo que otros atienden, tiene un impacto en el valor afectivo que le damos al objeto atendido. De hecho, en un estudio posterior demostraron que la preferencia por esos objetos mirados podía incluso modularse en función de la expresión emocional de la señal, prefiriendo los objetos mirados por expresiones emocionales de alegría frente a expresiones emocionales de disgusto (Bayliss et al., 2007). Aunque no podemos asociar una emoción a un señal de flecha, estos resultados son llamativos ya que podrían demostrar que cuantas más características sociales le damos a la señal, más diferencias podríamos encontrar entre señales sociales y no sociales (ver Dalmaso et al., 2020b para una revisión de variables sociales que pueden modular el efecto de *gaze-cueing*).

2.2 Aproximación cualitativa para estudiar la atención social

En base a los hallazgos descritos en párrafos anteriores, parece razonable pensar en dos ideas principales: 1) No hay diferencias cuantitativas en la magnitud de la orientación desencadenada por señales de flechas y miradas (Chacón-Candia, Román-Caballero, et al., 2023), y 2) la orientación desencadenada por la mirada de los otros es de alguna forma una señal atencional especial que podría modularse por procesos sociales como la teoría de la mente, el efecto de contacto ocular, la atención conjunta y la atención compartida, entre otros (Stephenson et al., 2021).

Como hemos comentado anteriormente, ambas señales comparten algunos procesos como la capacidad de dirigir la atención y comunicar información direccional, por lo que sería comprensible que funcionasen de la misma forma (Birmingham & Kingstone, 2009; Gibson & Kingstone, 2006). Sin embargo, también es posible que haya otros procesos relacionados con las propiedades sociales de la señal que se superpongan a los procesos de orientación general, sólo en los estímulos de la mirada. Por tanto es fundamental profundizar en paradigmas que estudien las diferencias entre estímulos desde una perspectiva cualitativa, en la que se pueda investigar la naturaleza y los procesos atencionales que cada tipo de señal puede desencadenar, más que la magnitud del efecto de orientación atencional que genera cada señal.

2.2.1 Diferencias cualitativas entre señales sociales y no sociales

Para estudiar las diferencias cualitativas en la orientación atencional desencadenada por señales sociales y no sociales se han utilizado diversas variantes y adaptaciones del *paradigma de gaze-cueing*. En los siguientes subapartados describimos varios de estos paradigmas.

De la orientación atencional a la selección atencional

Una de las primeras tareas que mostraron diferencias cualitativas fue la propuesta por Marotta y colaboradores (2012), quienes adaptaron una tarea de un estudio de Egly et al. (1994) en la que se estudiaba la atención al espacio y al objeto. La tarea adaptada consiste en presentar en una pantalla dos rectángulos (que denominaremos objetos) inclinados de modo que un extremo de cada rectángulo está colocado a la izquierda o a la derecha del punto de fijación donde se encuentra la señal central, y los otros extremos están por encima o por debajo de la señal central. La señal central no predictiva podía ser una cara esquemática con los ojos apuntando a la izquierda o la derecha, o una flecha apuntando a la derecha o a la izquierda. Después de la presentación de la señal aparecía el objetivo, que consistía en dos letras (X y O), que los participantes tenían que detectar y discriminar. Estos objetivos (letras) podían aparecer dentro de uno de los extremos de cualquiera de los rectángulos presentados. Generando varias posibilidades de presentación: a la izquierda o a la derecha de la señal central; y por encima o por debajo de la señal central. Para estudiar el efecto de orientación general entre flechas y miradas se compararon los ensayos en los que el objetivo aparecía en el objeto y posición señalada frente a cuando el objetivo aparecía en el objeto y la posición no señalada, mostrando resultados similares entre ambas señales. Por otra parte, para estudiar si la selección atencional se da en todo el objeto (orientación basada en el objeto) o sólo en una parte del objeto (orientación basada en la localización), se compararon los ensayos donde aparecía el objetivo en los extremos opuestos del objeto o rectángulo señalado frente a cuando aparecía en los extremos opuestos del objeto o rectángulo no señalado (Marotta et al., 2012). Los resultados de este experimento sugieren que con la mirada como señal central, la atención se dirige selectivamente a una parte concreta del objeto, aquella parte que esté siendo atendida por la mirada. Mientras con las flechas como señales centrales, la atención se dirige y se extiende a todo el objeto observado. Estos resultados muestran diferencias cualitativas entre flechas y miradas relacionadas con la selección atencional que ocurre tras la orientación. Ambas señales centrales (flechas y miradas) desencadenan una orientación y selección atencional equivalentes hacia los objetivos (letras) y los objetos (rectángulos). Sin embargo, la mirada produce una selección atencional a una localización concreta, es decir, la atención de los participantes no se esparce o disipa por todo el objeto, si no que se dirige a la localización concreta que se estaría mirando, y que se interpreta como localización de interés para la otra persona (Chacón-Candia, Lupiáñez, et al., 2023; Marotta et al., 2012).

Diversos estudios ponen de manifiesto que somos muy precisos detectando dónde está mirando otra persona (Wiese et al., 2012), por lo que identificar específicamente una zona de un objeto o localización señalados por la mirada no resultaría difícil. Marotta et al. (2012) al mostrar cómo la dirección de la mirada dentro de un contexto produjo un efecto de facilitación para prestar atención hacia posiciones concretas que estaban siendo observadas.

Este podría ser el inicio de un mecanismo más complejo de atención conjunta en el que percibir dónde mira concretamente el otro, no sólo orienta mi atención hacia ese lugar sino que permitiría seleccionar atencionalmente una localización específica o parte de un objeto específico, al que los demás están dirigiendo su atención (Calder et al., 2002; Ricciardelli et al., 2002), evitando distraerse con los numerosos estímulos del entorno.

De la selección atencional a los procesos cognitivos básicos

Es posible que para intentar capturar las diferencias cualitativas entre las señales no sociales y sociales haga falta no sólo saber cuánto nos orienta una señal y cómo seleccionamos la información en nuestro entorno en función de dicha señal, sino también cómo tratamos y usamos la información en función del tipo de señal que nos la proporcione, es decir, qué procesos cognitivos ponemos en marcha al orientarnos en una dirección y seleccionar un objetivo. En línea con esta idea, y conociendo el estrecho vínculo entre la atención y la memoria, sería razonable pensar que habría una mejora en la memoria de los objetos que han sido señalados por la mirada en comparación a los no señalados (Dodd et al., 2012). En este estudio, Dodd y colaboradores (2012) utilizaron un *paradigma de gaze-cueing* durante varios experimentos en el que los objetivos a detectar eran palabras que debían ser recordadas en una tarea posterior. Mientras que en algunos experimentos se les indicó que debían recordar las palabras, en otros experimentos no se les indicó, por lo que el recuerdo posterior sería incidental (no se les instruyó a recordar las palabras, por lo que la prueba de memoria fue inesperada). Sus resultados mostraron efectos de la orientación de la mirada (*gaze-cueing*) en el recuerdo de las palabras, cuando éstas se presentaron durante 250 ms y 500 ms, tanto cuando el recuerdo era intencionado, como cuando el recuerdo fue incidental. En general, se recordaban más las palabras de las localizaciones observadas (miradas por la cara) en comparación a las palabras de las localizaciones no observadas. Estos resultados fueron específicos de las señales centrales de miradas, ya que cuando se utilizaron flechas no predictivas como señales centrales no se encontraron diferencias en la codificación en memoria de las palabras que actuaban como objetivos.

Otras investigaciones posteriores que estudian la orientación de la mirada y la memoria de trabajo apoyaron estos resultados. Gregory y Jackson (2017) crearon un paradigma, basado en el *gaze-cueing*, que consistía en una señal central de una cara con mirada directa, que desplazaba su mirada a la izquierda o derecha, donde posteriormente podía aparecer o no el objetivo, creando ensayos válidos e inválidos. El objetivo consistía en un conjunto de cuadrados de colores, que debían codificarse, para posteriormente indicar si un color estaba presente o no en el ensayo anterior. El recuerdo fue mayor para los colores codificados en las localizaciones miradas (válidas) en comparación a los colores que parecían en las localizaciones no miradas (inválidas). Al igual que en los experimentos de Dodd et al. (2012), cuando se utilizaron flechas u otras señales no sociales (que incluían movimiento) las mejoras en la memoria de trabajo no se replicaron. No obstante, los efectos de orientación atencional general (medidos por RTs) fueron equivalentes con los tres tipos de señales. Estos resultados podrían indicar que la mirada como señal social parece ser más fiable para guiar la atención y mejorar la codificación de la información en memoria.

Estudios posteriores han replicado los efectos específicos de la mirada sobre la memoria de trabajo, por lo que parece ser un efecto estable (Gregory & Jackson, 2019; Gregory & Kessler, 2022). Apoyando estos resultados encontramos el trabajo de Nie et al. (2018) quienes investigaron cómo las retroseñales de la mirada modulan el mantenimiento de la información en la memoria de trabajo de forma automática. Para ello, utilizaron una tarea de control de cambios durante varios experimentos que consistió en presentar 2 ó 4 elementos a la derecha e izquierda del punto de fijación. Las personas participantes debían memorizar los elementos y sus ubicaciones. Posteriormente durante el intervalo de retención se presentaron retroseñales no predictivas en el centro de la pantalla que consistían en caras mirando, una señal no social con movimiento y una cara del revés. Todas las señales miraron o apuntaron a la derecha o la izquierda, lo que generó ensayos con ubicaciones señaladas y no señaladas. Además se instruyó a los participantes para ignorar las señales centrales. La tarea de los participantes consistía en indicar si el elemento presentado posteriormente era idéntico al presentado anteriormente en la misma ubicación. Los resultados mostraron que tanto las señales de caras mirando, como las no sociales con movimiento orientaron la atención automáticamente hacia las ubicaciones señaladas frente a las no señaladas. Sin embargo, sólo las señales de caras mirando desencadenaron una mejora en la memoria de trabajo, fortaleciendo el mantenimiento selectivo de elementos en la memoria de trabajo. Las retroseñales no sociales con movimiento y las caras invertidas no tuvieron ningún efecto en la memoria de trabajo lo que pone de manifiesto que ni la percepción del movimiento, ni las características perceptivas básicas son capaces de generar los mismos efectos. Estos autores concluyen que los efectos observados con la retro-señal de la mirada podrían indicar que los elementos que son atendidos conjuntamente tendrían una prioridad especial tanto en el procesamiento como en el mantenimiento de dicha información en la memoria de trabajo.

Estos estudios sugieren que los efectos de post-percepción o los procesos cognitivos que se ponen en marcha una vez que se selecciona atencionalmente un objeto o ubicación parecen claves en las diferencias cualitativas encontradas entre las señales sociales o no sociales (Chacón-Candia, Román-Caballero, et al., 2023).

De los procesos cognitivos básicos a la mentalización

Más allá de procesos cognitivos post-perceptuales, como la memoria, que podrían influir en las diferencias cualitativas encontradas entre ambas señales, es curioso cómo es posible generar efectos diferentes entre ambas señales incluso antes de la percepción inicial. Los estímulos sociales a diferencia de los estímulos no sociales, presentan una serie de características inherentes a su significado y relevancia social. Por ejemplo, las señales de la mirada no sólo dirigen la atención a una dirección, sino que pueden indicar la intención de actuar hacia un objetivo, mostrando no sólo el foco de atención e interés de alguien, si no también pudiendo predecir su intención y con ello su comportamiento motor posterior (Huang et al., 2015). Sin embargo, las señales no sociales como por ejemplo las flechas no pueden mostrar de forma tan automática esa intención, generalmente hay que otorgárselas explícitamente. Por lo tanto, la intención que asociamos a las señales tanto de forma automática (por sus características físicas) como de forma más controlada (en base a nuestros objetivos y pensamientos) podrían modular de alguna forma la respuesta a dichas señales. Dicho de otra forma, las señales de la mirada y las flechas podrían ser guiadas por un procesamiento de arriba-abajo.

En línea con esta idea encontramos el estudio de Capellini y colaboradores 2019, en el que investigan si la exclusión social puede afectar a la orientación y seguimiento de la mirada (efecto de *gaze-cueing*). El experimento consistía en un juego virtual en el que las personas participantes podían ser excluidos o incluidos. Posteriormente, los participantes realizaron una tarea de seguimiento ocular o *gaze-cueing*. Los resultados mostraron cómo el efecto de la mirada (efecto de *gaze-cueing*) se vio modulado por si habían sido previamente excluidos o no en el juego anterior. Los participantes que habían sido excluidos mostraron un efecto de seguimiento de la mirada más pequeño en comparación a los participantes que no habían sido excluidos. Al sustituir las caras por señales de flecha este efecto no se producía. Esto pone de relieve cómo la exclusión social afecta sólo a las señales de la mirada. Los autores sugieren que la mirada desviada podría estar percibiéndose como una señal de exclusión, haciendo que los participantes excluidos en el juego principal se desvinculen posteriormente de una posible interacción social.

Otro estudio relevante en esta línea es el trabajo de Gobel et al. (2018) en el que utilizan una versión interpersonal del paradigma de costes y beneficios (Posner, 1980). La diferencia con el paradigma original es que hacen creer a los participantes que dependiendo del ensayo pueden estar interactuando con un compañero/a o con un ordenador. En la mitad de los ensayos, la señal se movería de acuerdo a donde había mirado previamente el compañero/a invisible y en la otra mitad de los ensayos el movimiento de la señal lo generaba un ordenador de forma aleatoria. El objetivo del estudio fue investigar si la relevancia social de una señal, a priori no social, podría influir en la orientación espacial. Los resultados mostraron que manipular la creencia sobre si el movimiento de la señal era de origen social o generado por ordenador influyó en el efecto de orientación espacial, a pesar de que la señal siempre fue la misma. La magnitud del efecto de inhibición de retorno fue mayor en los ensayos donde el origen del movimiento de la señal se atribuyó a un compañero/a invisible. Además, el efecto fue modulado por el rango social del supuesto compañero/a de interacción y por la idea de si el compañero/a estaba comprometido en la misma tarea o en una tarea diferente. Este estudio pone de manifiesto que utilizando la misma señal atencional no social, las creencias a priori sobre la relevancia social pueden influir en la orientación espacial interpersonal (Gobel et al., 2018).

En resumen, es relevante tener en cuenta que la atención que desencadena una señal no sólo puede estar guiada por las características físicas de la señal y sus significados aprendidos, sino también por un procesamiento más controlado, donde la representación mental que se hace, inicialmente, de la señal genera una respuesta diferencial importante. Esta idea abriría el debate de si la atención que se dirige a las señales sociales ocurre bajo un procesamiento automático o por el contrario ocurre por un procesamiento más controlado, en el cual podríamos interferir de forma voluntaria.

2.2.2 Diferencias cualitativas entre flechas y miradas como estímulos objetivos.

Paradigma de Interferencia Espacial

De acuerdo a la literatura descrita anteriormente podemos decir que incluso cuando la magnitud de los efectos de orientación atencional de las señales sociales y no sociales permanece equivalente (Chacón-Candia, Román-Caballero, et al., 2023), se encuentran diferencias cualitativas entre ambas señales al utilizar variantes del paradigma de orientación espacial. Estas diferencias cualitativas parecen encontrarse no sólo en los procesos que ocurren tras la orientación que generan las señales (Chacón-Candia, Lupiáñez, et al., 2023; Dodd et al., 2012; Gregory & Jackson, 2017; Marotta et al., 2012), sino también en la intención que de forma automática o controlada le asignamos a las señales (Capellini et al., 2019; Gobel et al., 2018). No obstante, en todas las tareas y variaciones del paradigma original que hemos revisado, los estímulos sociales o no sociales actúan como señales que orientan la atención hacia una ubicación u objetivo que debe ser atendido, para poder responder adecuadamente.

Recientemente, se han encontrado diferencias cualitativas más robustas entre estímulos sociales y no sociales utilizando un paradigma de interferencia espacial o stroop espacial, donde los estímulos sociales y no sociales se utilizan como objetivos a los que hay que responder y no como señales (Cañadas & Lupiáñez, 2012; Marotta et al., 2018a).

El paradigma de interferencia espacial o Stroop espacial consiste en discriminar la dirección de una flecha o una palabra con significado direccional, que aparecen a la izquierda o a la derecha del punto de fijación. Normalmente se observa que las respuestas son más rápidas y precisas cuando la dirección de la flecha o la palabra es congruente con el lado de la pantalla donde se presenta (p.ej., una flecha apuntando hacia la izquierda, que se presenta en el lado izquierdo de la pantalla), en comparación a los ensayos donde la dirección de la flecha o la palabra es incongruente con su posición (p.ej., una flecha apuntando hacia la izquierda, que se presenta en el lado derecho de la pantalla), dando lugar a el clásico efecto de interferencia espacial o congruencia espacial (Logan, 1980; Lupiáñez & Funes, 2005). Este efecto ocurre por la interferencia que se genera entre la dimensión espacial relevante del objetivo (la direccionalidad de la flecha) y su dimensión espacial irrelevante (el lugar en el que se presenta la flecha) (Kornblum et al., 1990; C. Luo & Proctor, 2013). Cañadas y Lupiáñez (2012) utilizaron el paradigma de interferencia espacial sustituyendo las flechas y palabras, por caras completas y ojos recortados que aparecían a la izquierda o la derecha del punto de fijación. Sorprendentemente, cuando se debía discriminar la dirección de la mirada, el efecto de congruencia espacial clásico se revirtió, creando el efecto de congruencia revertida, en el que los participantes son más rápidos y precisos en los ensayos donde la dirección de la mirada y la localización de la cara son incongruentes (p.ej., una cara o unos ojos mirando hacia la izquierda, que se presenta en el lado derecho de la pantalla) en comparación a los ensayos en los que la dirección de la mirada y la localización coinciden (ensayos congruentes; p.ej., una cara o unos ojos mirando hacia la izquierda, que se presenta en el lado izquierdo de la pantalla).

Años más tarde Marotta y colaboradores (2018) adaptaron el paradigma de interferencia espacial para estudiar diferencias entre estímulos utilizando un par de flechas y un par de ojos, con la intención de igualar las características físicas entre los estímulos. Los estímulos se presentaron en bloques separados. Los resultados replicaron los hallazgos obtenidos por Cañadas y Lupiáñez (2012) mostrando un efecto de congruencia estándar con las flechas (respuestas más rápidas en los ensayos congruentes en comparación a los ensayos incongruentes) y un efecto de congruencia revertida con la mirada (respuestas más rápidas en los ensayos incongruentes en comparación a los ensayos congruentes) (**Figura 3**).

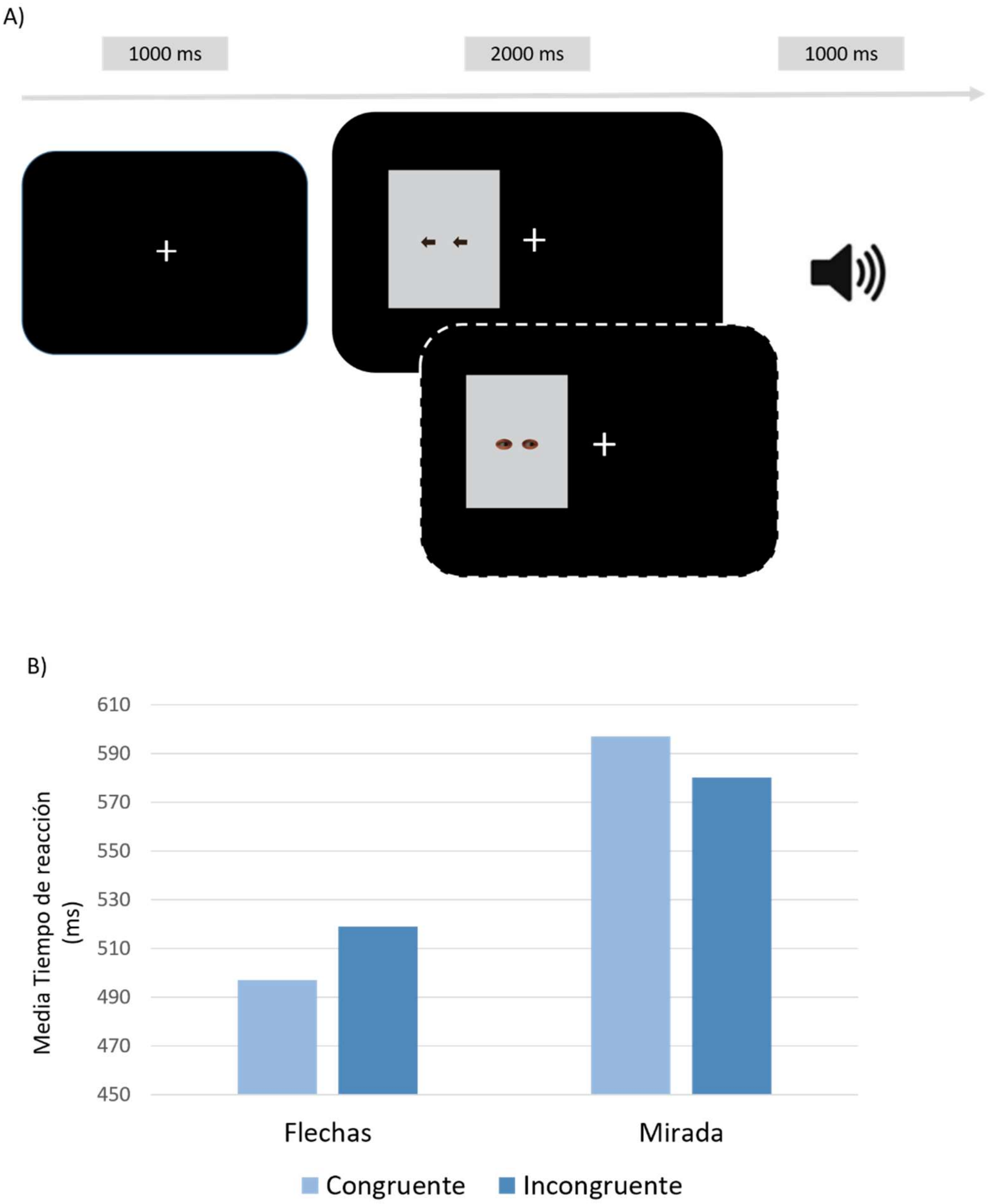

Figura 3. A) Representación del Paradigma de Interferencia Espacial de (para ver la figura original ir a Marotta et al. (2018). **B)** La gráfica representa los resultados de congruencia espacial observados por Marotta et al. (2018).

Esta disociación en los efectos de congruencia entre ambos estímulos encaja con la idea de que el procesamiento atencional de la mirada podría representar un proceso atencional único, y cualitativamente distinto de los mecanismos atencionales desencadenados por estímulos no sociales, como las flechas. Estos hallazgos han sido ampliamente replicados en la última década tanto con caras enteras (Aranda-Martín et al., 2022; Cañadas & Lupiáñez, 2012; S. Jones, 2015; Marotta et al., 2022; Torres-Marín et al., 2017) como utilizando sólo un par de ojos (Ishikawa et al., 2021; Marotta et al., 2018, 2019).

Hipótesis explicativas del Efecto de Congruencia Revertida

En los últimos años se ha avanzado en la explicación al efecto de congruencia revertida que ocurre con los estímulos de la mirada, no obstante, la naturaleza de este efecto aún no está clara. Parte del objetivo de esta tesis es profundizar en su explicación.

A continuación describimos las primeras hipótesis explicativas sobre el efecto de congruencia revertida que aparece con los estímulos de la mirada.

De acuerdo a los primeros estudios (Cañadas & Lupiáñez, 2012; Marotta et al., 2018a), la mediación del contacto ocular podría explicar el efecto de congruencia revertida. De hecho, cuando la mirada se presenta a la izquierda y mira a la derecha (ensayo incongruente), está mirando hacia el centro, en la dirección adecuada para hacer contacto visual con el participante. Por el contrario, si la cara objetivo se presenta a la izquierda y mira a la izquierda (ensayo congruente), la mirada se desvía del participante, lo que estaría facilitando el procesamiento de los ensayos incongruentes de la mirada en comparación a los ensayos congruentes. Este efecto social no estaría presente cuando la señal espacial es una flecha, ya que estas señales tienen una propiedad direccional como la mirada, pero no un significado social e intenciones. El efecto de contacto ocular estaría mediado por procesos relacionados con la teoría de la mente (Cañadas & Lupiáñez, 2012), en otras palabras, se podría decir que las flechas pueden indicar la dirección pero no te miran (Marotta et al., 2018a). De hecho, como queda patente en el Capítulo 1 de esta tesis, la mirada directa no sólo se procesa más rápido que una mirada desviada sino que capta más nuestra atención e influye en nuestro comportamiento. En línea con la hipótesis de contacto ocular y considerando que la mirada podría dirigirse al participante, y que éste no podría ignorar su relevancia biológica, una posible explicación estaría relacionada con las teorías motivacionales de acercamiento/evitación. Esta explicación sugiere que la mirada directa (ensayo incongruente) generaría una tendencia motivacional de acercamiento ante una posible interacción social y por lo tanto es lógico que su procesamiento sea más rápido, mientras que la mirada desviada (ensayo congruente) generaría una tendencia motivacional de evitación del observador, lo que dificulta su procesamiento (Hietanen et al., 2008).

Otra explicación plausible sugiere que en los ensayos incongruentes, la mirada en vez de mirar al participante e iniciar un intento de contacto ocular, podría estar mirando al punto de fijación, a la misma vez que el participante también está orientando su mirada al punto de fijación, por lo que participante y estímulo comparten un mismo objeto de atención generando un acto atención conjunta. Esto facilitaría el procesamiento de la mirada en los ensayos incongruentes frente a los congruentes (Cañadas & Lupiáñez, 2012; Edwards et al., 2020).

La mayoría de las hipótesis que explican el efecto de congruencia revertida, lo hacen basándose en la naturaleza social de la mirada, una característica que no tiene la flecha. Aunque ambas comparten la capacidad de indicar y orientar la atención en una dirección determinada (Gibson & Kingstone, 2006).

Por una parte, la posible naturaleza social del efecto se apoya en investigaciones donde el efecto de congruencia revertida se modula en función de la expresión emocional (Jones, 2015; Torres-Marín et al., 2017). En esa misma línea, las personas con rasgos autistas no muestran las modulaciones emocionales del efecto (Marotta et al., 2022). Además, un estudio reciente (Aranda-Martín et al., 2022), utilizando este paradigma con población infantil y adolescentes, mostró que el efecto de congruencia revertida no aparece hasta la adolescencia temprana (aprox. a los 12 años), lo que significa que este efecto específico de la mirada necesita de cierta maduración de los procesos cognitivos implicados en la atención social para surgir, al igual que parece ocurrir con los efectos de inhibición de retorno (Jingling et al., 2015).

Por otra parte, aunque la mayoría de las hipótesis explicativas se centran en la mirada y su naturaleza social, es posible que también explorando los procesos de orientación de la atención que tanto flechas como miradas son capaces de generar de forma similar, nos acerquemos a entender el efecto de congruencia revertida.

Durante esta tesis doctoral utilizaremos el paradigma de interferencia espacial, intentando ahondar en la explicación de la naturaleza del efecto de congruencia revertida y los mecanismos que estarían a la base de las diferencias cualitativas encontradas entre ambos estímulos (ver Capítulo 4, Objetivos de la Tesis).

CAPÍTULO 3. Bases neurales de la atención social

En los capítulos anteriores hemos descrito qué es la atención social y cómo podemos estudiarla. Además se ha descrito la importancia de la mirada como estímulo atencional y sus similitudes y diferencias con otro tipo de señales de orientación no sociales, como las flechas. Los datos comportamentales nos proporcionan información sobre los procesos cognitivos que subyacen a la atención social, así como los cambios atencionales que genera la dirección de la mirada de los otros. Sin embargo, es importante completar estos hallazgos haciendo una revisión sobre los mecanismos neurales que sustentan estos procesos. Por ello, en este capítulo nos proponemos revisar la literatura sobre las bases neurales que sustentan los procesos de la atención social.

Durante este capítulo se ofrece una visión general de los circuitos cerebrales implicados en la atención social, con especial énfasis en la percepción y procesamiento del rostro y la dirección de la mirada. El estudio de las bases neurales de la atención social es bastante amplio por lo que aquí nos centraremos en mayor medida en los estudios que utilizan el *paradigma de gaze-cueing* para estudiar las diferencias en la orientación atencional entre estímulos sociales y no sociales.

3. 1 Bases neurales de la percepción de la cara y la mirada

No hay duda de que el rostro de otras personas es uno de los estímulos más importantes en nuestro día a día; procesar la información del rostro nos ayuda a interaccionar con nuestro entorno, especialmente en el contexto social. En concreto, el procesamiento de la región de los ojos y la dirección de la mirada juega un papel fundamental en la comunicación social. Dada la relevancia de los ojos y la dirección de la mirada, algunos autores consideran que el cerebro humano ha desarrollado un sistema cognitivo y neural específico para su procesamiento (S. Baron-Cohen, 1995)

Los estudios realizados con macacos confirman la idea de que habría regiones neurales específicas del procesamiento del rostro y de la mirada. Perrett et al. (1992) encontraron células que responden selectivamente a las caras y a la orientación de la mirada y el cuerpo, en regiones del surco temporal superior (STS) y del giro temporal inferior. Algunos estudios apuntan incluso a células que responderían a la dirección de la mirada únicamente dentro del STS (De Souza et al., 2005). Sin embargo, es posible que STS simplemente procese el movimiento biológico, y la mirada se considere un tipo de movimiento biológico (Puce & Perrett, 2003). No obstante, las células de las regiones del STS que responden selectivamente a las caras y los ojos parecen ser parte de una red neural más amplia y especializada en el procesamiento de las interacciones sociales (Itier & Batty, 2009). Aunque aún hace falta más investigación tanto con primates, como humanos que expliquen las bases neurales que subyacen al comportamiento de orientación social, es probable que el procesamiento de los estímulos u objetos animados y su foco atencional sea rápido y automático. Iniciándose en circuitos subcorticales que irían desde el colículo superior por el núcleo pulvinar hasta la amígdala, para posteriormente conectarse con regiones del neocórtex para un procesamiento más profundo que facilitase la atención social (J. T. Klein et al., 2009; Senju & Johnson, 2009).

En los estudios con humanos también se pueden diferenciar dos redes neurales, una subcortical y otra cortical, lo que muestra la existencia de una amplia red neural implicada en la atención social. Esta red estaría dentro del denominado “cerebro social”, que incluye áreas que se encargan de la percepción facial, la percepción de la mirada, la atención, la emoción y la atribución de estados mentales (Hadders-Algra, 2022; Itier & Batty, 2009; Nummenmaa & Calder, 2009). Aunque ambos hemisferios participan en el cerebro social, parece existir una lateralización de esta función en el hemisferio derecho, siendo su participación predominante (Duchaine & Yovel, 2015; Freiwald et al., 2017).

Estudios con resonancia magnética funcional sugieren que existe una red general especializada en el procesamiento de rostros, la cual incluiría varias regiones de la corteza occipito-temporal (Bernstein & Yovel, 2015; Haxby et al., 2000; O`Toole et al., 2002). Investigaciones más recientes muestran que la participación de una u otra región depende de los paradigmas utilizados y del contexto, involucrando flujos de información bidireccionales, tanto del procesamiento de abajo-arriba como del procesamiento de arriba-abajo (Hadders-Algra, 2022).

Haxby y colaboradores (2000) propusieron un modelo neural del procesamiento del rostro, que incluye el giro occipital inferior, el giro fusiforme y la parte posterior del surco temporal superior (pSTS). Juntos forman un "sistema central” encargado del análisis visual de las diferentes características y partes del rostro (Haxby et al., 2000; Nummenmaa et al., 2010). El giro occipital inferior, que incluye al área occipital de la cara, es la primera región cortical que se encarga de procesar de forma temprana las características básicas del rostro, un paso esencial para el posterior procesamiento de rasgos faciales complejos en regiones corticales de orden superior (Pitcher et al., 2011). El giro occipital inferior se conecta con el giro fusiforme creando la vía ventral. El giro fusiforme es el encargado del reconocimiento de rostros y de procesar las denominadas características invariables del rostro, aquellas que no cambian o cambian muy lentamente a lo largo del tiempo, como la identidad facial (Bernstein & Yovel, 2015). El giro occipital inferior también está conectado con la parte posterior del surco temporal superior, formando la vía dorsal, que se encarga de procesar las características cambiantes o dinámicas del rostro como la dirección de la mirada, el movimiento de la boca al hablar, las expresiones emocionales, etc. (Bernstein & Yovel, 2015; Haxby et al., 2000). Ambas vías son independientes y tienen funciones diferentes, no obstante funcionan en paralelo y están densamente conectadas entre sí (Kessler et al., 2021).

Varios estudios han hecho hincapié en el papel crucial del surco temporal superior en la percepción de la mirada y la codificación de su dirección. Estudios con macacos han mostrado cómo la parte anterior y posterior del surco temporal superior contienen células específicas destinadas al procesamiento de la orientación de la mirada, la cabeza y el cuerpo (Carlin & Calder, 2013; Hadders-Algra, 2022).

Estudios con humanos muestran cómo la parte anterior del surco temporal superior responde ante la dirección de la mirada, concretamente hacia la izquierda o derecha de forma específica (Carlin & Calder, 2013). Mientras, la parte posterior del surco temporal superior parece ser fundamental para determinar cómo se procesa la mirada a nivel social, es decir, si hay una intención social detrás de la dirección de la mirada y/o si ésta se percibe como un acto comunicativo, por ejemplo, a través del contacto visual o como un acto de atención conjunta con una mirada desviada (Nummenmaa & Calder, 2009; Pfeiffer et al., 2013; Redcay et al., 2010; Senju & Johnson, 2009). Además de su papel en la percepción de la mirada, la parte posterior del surco temporal superior también está implicado en la atribución mental y la teoría de la mente, lo que subraya su papel crucial en el procesamiento de la información social y el movimiento biológico significativo (Yang et al., 2015).

A pesar de que el STS está implicado en la percepción de la dirección de la mirada, la forma en que parece interactuar con otras regiones se ve afectada por la tarea utilizada y el contexto (Burra et al., 2018). Además, el procesamiento y la interpretación de la mirada requieren no solo la participación del STS, sino también la de una red neuronal más amplia implicada en la atención espacial y en los procesos cognitivos que desencadenan la orientación de la mirada y su percepción (Bernstein & Yovel, 2015; Hadders-Algra, 2022). Esta red neural más extensa implica también a regiones como la amígdala, el complejo temporal inferior, MT/V5, las cortezas parietales, la corteza cingulada anterior y posterior, y las cortezas prefrontales medial y lateral (Nummenmaa & Calder, 2009). Revisiones recientes hacen hincapié en que las regiones implicadas en el procesamiento de la mirada, si bien forman parte del "cerebro social", dependen del tipo de paradigma utilizado y del procesamiento que el estímulo o señal de la mirada desencadene (Schurz et al., 2021). Hadders-Algra (2022), separa las regiones implicadas en función de los procesos que la mirada genera. Por ejemplo, la mirada mutua involucra al STS y a la corteza prefrontal, mientras que los cambios de orientación de la mirada implican al STS, el surco intraparietal y la giro fusiforme. Posteriormente, si se genera atención conjunta entrarían en juego la corteza prefrontal medial y la unión temporo-parietal. Estudios anteriores ya han descrito diferencias entre las regiones cerebrales destinadas a la mirada directa o efecto de contacto ocular versus la mirada desviada. De acuerdo a la literatura, parece que regiones como el giro fusiforme derecho, parte anterior y posterior del surco temporal superior derecho, la corteza orbitofrontal y la amígdala bilateral son más sensibles al efecto de contacto ocular o mirada directa (Senju & Johnson, 2009). Mientras que en el trabajo de Hoffman y Haxby (2000) se encontró una mayor respuesta en regiones de la corteza parietal posterior, y el surco intraparietal para la mirada desviada en comparación a la mirada directa. El surco intraparietal forma parte de la red fronto-parietal (descrita en párrafos posteriores) que participa en la orientación espacial de la atención, por lo que percibir la mirada desviada de otra persona podría implicar procesos de atención espacial de dominio general (Corbetta & Shulman, 2002).

Lockhofen y colaboradores (2014) también sugieren que las regiones parietales podrían estar implicadas en la percepción de la mirada, concretamente el surco intraparietal superior y la unión temporo-parietal, reflejando la implicación del sistema atencional en la codificación y orientación de la atención a la mirada de la otra persona. En la misma línea y dado que el ser humano muestra una tendencia automática a seguir la dirección de la mirada de los demás, cambiando su foco atencional en función de la mirada del otro, es plausible pensar que las redes atencionales del modelo de Corbetta et al. (2008) también podrían estar implicadas en los cambios atencionales que generan las señales de la mirada. Este modelo atencional (Corbetta et al., 2008; Corbetta & Shulman, 2002) plantea la existencia de dos sistemas atencionales separados a nivel neural; un sistema frontoparietal dorsal que incluye al lóbulo parietal superior, surco intraparietal y los campos oculares frontales. Y otro sistema frontoparietal ventral formado por el giro supramarginal, la unión temporo parietal, la parte posterior del surco temporal superior, la corteza prefrontal medial e inferior y la ínsula anterior. El sistema de atención dorsal está implicado en la orientación de la atención desencadenada por objetivos (atención voluntaria) o los procesos de “arriba-abajo”. Este sistema tiene un papel particular en la selección atencional de objetivos y localizaciones. El sistema de atención ventral, por otro lado, estaría implicado en los cambios de atención hacia estímulos relevantes pero inesperados (atención involuntaria), mediante un proceso de “abajo-arriba”. Se propone que el sistema ventral interrumpe el procesamiento en curso para reorientar la atención hacia esos estímulos que pueden ser importantes. Los cambios de atención que desencadena la mirada de otra persona son cambios generalmente automáticos e involuntarios, hacia donde la otra persona está mirando, aunque también pueden estar guiados por objetivos o intenciones, por lo que es posible que ambos sistemas atencionales estén implicados en la percepción de la dirección de la mirada (Driver et al., 1999; Friesen & Kingstone, 1998; Nummenmaa & Calder, 2009).

Cuando seguimos la mirada de otra persona, reorientamos nuestra atención hacia su foco atencional, participando en un acto de atención conjunta hacia otra persona. Según la literatura, la corteza prefrontal medial, la unión temporo- parietal, y la parte posterior del surco temporal superior participan cuando seguimos la mirada de otra persona e iniciamos un acto de atención conjunta, sincronizando nuestra atención con la de otra persona (Carlin & Calder, 2013; Hadders-Algra, 2022; Nummenmaa & Calder, 2009). La región anterior de la corteza prefrontal medial estaría involucrada cuando otros inician el acto de atención conjunta, mientras que otras regiones, como el núcleo estriado ventral se activarían cuando nosotros mismos iniciamos la atención conjunta (Schilbach et al., 2010). Se cree, por tanto, que la participación de la corteza prefrontal medial en el procesamiento de la mirada podría estar asociada a procesos de mentalización y teoría de la mente (ToM) (Schurz et al., 2021).

3.2 Bases neurales de la orientación atencional desencadenada por señales sociales y no sociales

La relación entre la orientación de la atención y la dirección de la mirada ha sido ampliamente estudiada a nivel comportamental usando el *paradigma de gaze-cueing* propuesto por Friesen y Kingstone (1998). El uso de este paradigma, como hemos descrito anteriormente (ver apartado 2.1), tiene como objetivo estudiar cómo las señales de la mirada son capaces de orientar nuestra atención.

Se propone que la atención a la mirada puede representar un proceso de orientación atencional único que refleja el funcionamiento de un mecanismo cognitivo (Farroni et al., 2002) y neural especializado, responsable de dirigir la atención hacia la información socialmente relevante. Este mecanismo neural subyacente a la orientación atencional de la mirada sería independiente del mecanismo neural de orientación de otras señales direccionales pero no sociales, como las flechas (Kingstone et al., 2000; J Ristic et al., 2002).

Uno de los primeros estudios que investigó los mecanismos neurales de la orientación social fue el trabajo de Kingstone y colaboradores (2000), que utilizaron una versión lateralizada del *paradigma de gaze-cueing* en dos pacientes con "cerebro dividido". Cada uno de estos pacientes tenía lateralizado el procesamiento facial en un hemisferio diferente. Los resultados mostraron que los efectos de orientación automáticos de la mirada en cada paciente aparecieron en hemisferios diferentes, concretamente en el hemisferio especializado en el procesamiento de rostros. Estos efectos no se encontraron cuando se utilizaron señales no sociales (J Ristic et al., 2002).

Otros estudios con pacientes con un desarrollo atípico de la cognición social también han mostrado diferencias entre la orientación atencional de la mirada y las flechas. Se ha comparado la ejecución en *paradigmas de gaze-cueing* de pacientes con esquizofrenia frente a controles sanos. Los resultados mostraron una disminución del efecto de facilitación, que genera la orientación de la mirada, en los pacientes esquizofrénicos en comparación a los controles sanos (Akiyama et al., 2008; Catalano et al., 2020; Dalmaso et al., 2013). Otros pacientes con trastornos del espectro autista o trastorno de atención e hiperactividad también muestran un patrón de resultados diferentes cuando son evaluados con paradigmas similares al *gaze-cueing*, mostrando dificultades en la orientación de la mirada, pero no frente a otros estímulos direccionales no sociales (Marotta et al., 2013, 2014; Ristic et al., 2005)

Algunos de los primeros estudios con población sana muestran resultados mixtos al comparar la activación cerebral desencadenada por ambas señales (flechas y miradas). Por un lado, en Kingstone et al. (2004) realizaron un estudio con resonancia magnética funcional en el que les mostraron a los participantes una señal central, que consistía en un dibujo, que según las instrucciones podía percibirse como una cara con unos ojos indicando una dirección o como un coche con unos faros (estímulo direccional pero no social). Los resultados mostraron que el STS sólo se activó cuando los participantes recibieron instrucciones de interpretar la señal como una cara, pero no como un coche (a pesar de que ambos estímulos generaban una orientación automática de la atención equivalente a nivel comportamental). La respuesta del STS ha demostrado cierta especificidad al movimiento de los ojos y a los cambios de la mirada, en mayor medida que otras señales direccionales como las flechas, posiblemente por su papel en la transmisión de información socialmente relevante (Hooker et al., 2003; Materna et al., 2008). No obstante, el papel del STS ha sido cuestionado y su participación podría no ser exclusiva del procesamiento de las señales de la mirada (Hein & Knight, 2008).

Por otro lado, Tipper y colaboradores (2008) también utilizaron una señal central ambigua, que podía percibirse como una flecha o un ojo. Sus hallazgos mostraron áreas cerebrales superpuestas en la percepción de ambas señales, incluyendo regiones fronto-parietales pertenecientes a las redes de atención dorsal y ventral. Además, los resultados mostraron regiones occipitales y frontales de la red ventral, con una respuesta más intensa para las señales consideradas como ojos mirando, en comparación a las señales consideradas como flechas apuntando. Los autores concluyeron que las señales de flechas y miradas comparten el mismo sustrato neural, el cual podría funcionar de forma más efectiva para las señales de la mirada.

Los hallazgos electrofisiológicos y de neuroimagen que utilizan paradigmas de orientación atencional entre flechas y miradas han arrojado en general resultados dispares sobre las disociaciones de la actividad cerebral entre la mirada y las flechas. De hecho, es importante tener en cuenta que las diferencias encontradas en algunos de los primeros trabajos (Kingstone et al., 2004; Tipper et al., 2008) pueden estar ensombrecidas por las características perceptuales de los estímulos, los cuales difieren en cuanto a la información física y perceptiva más básica. Por lo que no es extraño que ambos estímulos impliquen a regiones diferentes para su procesamiento, las cuales pueden no estar relacionadas con la orientación atencional per se. Esto implica que es imprescindible eliminar las diferencias perceptuales del procesamiento visual de bajo nivel entre ambas señales, para poder estudiar exclusivamente el procesamiento de la orientación atencional (Birmingham & Kingstone, 2009).

En resumen, la revisión de la literatura previa que compara la orientación social de las señales de la mirada frente a la orientación de señales no sociales, muestra resultados inconclusos. Algunos estudios han observado activaciones similares para las señales sociales y no sociales en las regiones frontoparietales (Brignani et al., 2009; Callejas et al., 2014; Greene et al., 2009; Sato et al., 2009; Zhao et al., 2017), mientras que otros estudios mostraron una activación cortical diferente para las señales sociales, caracterizada por una mayor activación de la parte posterior del surco temporal superior o de las cortezas extraestriadas bilaterales para la mirada frente a las flechas (Engell et al., 2010; J. K. Hietanen et al., 2006; Lockhofen et al., 2014).

Durante los últimos años ha aumentado la publicación de trabajos que exploran las redes neurales que subyacen a la orientación atencional desencadenada por la mirada. Sin embargo, sorprendentemente, son menos los trabajos que utilizando versiones de los paradigmas clásicos de orientación (*gaze-cueing*), estudian las redes neurales de la orientación atencional de señales sociales en comparación con las redes neurales de la orientación a señales no sociales. Describimos en los dos siguientes sub-apartados algunos de los trabajos más importantes usando variaciones del *paradigma de gaze-cueing*, que muestran tanto diferencias como similitudes entre las bases neurales de la orientación atencional producida por flechas y miradas. Con el objetivo de facilitar la lectura y la información presentada, seleccionamos en cada sección dos de los trabajos más relevantes.

3.2.1 Correlatos neurales diferentes entre señales atencionales sociales y no sociales

Hietanen y colaboradores (2006) usaron un paradigma de orientación atencional en el que compararon dos tipos de señales centrales no predictivas, una mirada esquemática y una flecha, con el objetivo de investigar los cambios automáticos de la atención que genera cada tipo de señal, intentando eliminar la actividad neural relacionada con las etapas tempranas del procesamiento perceptivo de las señales, que indiscutiblemente son diferentes (ver Kingstone et al., 2004). Los resultados principales mostraron que, a nivel comportamental, se observaron efectos de facilitación para las localizaciones señaladas en comparación con las no señaladas en ambas señales (flechas y miradas). Los datos a nivel neural sugirieron redes neurales parcialmente separadas entre la orientación de la atención desencadenada por la mirada frente a la desencadenada por las flechas. Descubrieron que la actividad de regiones occipito-temporales de ambos hemisferios (giro occipital medio e inferior) se superponía para las señales de flechas y miradas. Sin embargo las áreas activadas para las flechas fueron más extensas en comparación a las señales de la mirada y requerían del hemisferio izquierdo. Además, la orientación desencadenada por las flechas frente a la desencadenada por la mirada, activó áreas parietales y frontales selectivamente. Con estos datos los autores discuten el hecho de que las señales de la mirada dependan de un proceso de orientación más automático, mientras que las flechas necesiten activar una red más amplia que implique una orientación voluntaria y más controlada de la atención.

Joseph y colaboradores (2015) también encontraron un patrón similar de activaciones diferenciales para las señales de flechas y miradas. En su estudio se centraron en los procesos de reorientación de la atención. Hipotetizaron que las señales de la mirada podrían atraer la atención automáticamente por su relevancia social, mientras que las flechas podrían necesitar de un proceso más controlado. A nivel neural esta idea se podría ver reflejada en los proceso de reorientación de la atención tras una señal exógena, la red de atención ventral podría verse implicada de forma diferente para cada una de las señales. Los resultados comportamentales demostraron que tanto las flechas como la mirada orientan la atención de forma automática. Los datos de neuroimagen de ambas señales mostraron que el sistema atencional ventral, en particular la unión temporoparietal y el lóbulo parietal inferior, se activaron cuando los participantes reorientaban la atención tras la presentación de señales de mirada no válida, pero no tras la presencia de señales de flecha no válidas. En este trabajo, los autores (Joseph et al., 2015) sugieren que la dirección de la mirada puede suscitar automáticamente expectativas sobre la intención de un actor, y que la unión temporo-parietal se activaría para redirigir la atención. Además, se descubrieron otras activaciones en la red de atencional dorsal en respuesta a señales de mirada no válidas, que implicaban a regiones del lóbulo parietal superior junto los campos oculares frontales, lo que los autores concluyen que podría reflejar la redirección de la atención hacia el objetivo, en la localización no señalada.

3.2.2 Correlatos neurales similares entre señales atencionales sociales y no sociales

Los siguientes trabajos nacen de la idea de que las señales sociales y no sociales de orientación atencional compartirían mecanismos neurales, por el hecho de que ambas señales generarían cambios automáticos de la atención. En base a esto, Sato y colaboradores (2009) propusieron que los mecanismos neurales que subyacen a la orientación desencadenada por la mirada, una mano señalando y una flecha serían comunes. Utilizaron resonancia magnética funcional para estudiar la actividad cerebral mientras los participantes observaban pasivamente señales direccionales y no direccionales centrales. Sus hallazgos mostraron mecanismos neurales comunes para los tres tipos de señal en el hemisferio derecho, específicamente en regiones del surco temporal superior, el lóbulo parietal inferior, el giro frontal inferior y regiones occipitales. Estos resultados apoyan la hipótesis de que independientemente del tipo de señal se producen cambios automáticos de la atención, activando la red fronto-parietal ventral, encargada de la reorientación de la atención. Aunque regiones temporales y la amígdala se activaron sólo para las flechas y las miradas respectivamente, los autores consideran que no había diferencias claras entre los tres tipos de estímulos y que las escasas diferencias encontradas podrían deberse a las características de su propia tarea.

Callejas y colaboradores (2014) demostraron que las regiones frontoparietales dorsales y ventrales para orientar y reorientar la atención al espacio se activan tanto por señales simbólicas como señales sociales. Sin embargo, dependiendo del tipo de señal, estos mecanismos se activan de forma diferente, resultados que podrían apoyar los descritos por otros autores (Greene et al., 2009). Así, las regiones frontoparietales dorsales incluyendo el surco intraparietal izquierdo y el córtex occipital bilateral MT+/lateral sólo mostraron efectos de orientación para las claves simbólicas, mientras que el surco intraparietal posterior derecho mostró mayores efectos de facilitación tras las señales de la mirada. Además, un análisis de conectividad funcional mostró que las regiones selectivas de la cara tienen una mayor conectividad con la parte posterior derecha del surco intraparietal, la parte posterior del surco temporal superior y el giro frontal inferior durante la señalización de la mirada, lo que concuerda con la hipótesis de que las regiones selectivas de la cara (giro occipital inferior, giro fusiforme, STS) pueden extraer información de la mirada y transmitirla a redes de atención frontoparietales ventrales y dorsales durante la señalización de la mirada.

En general, tanto en los estudios que encuentran diferencias como similitudes entre flechas y miradas, se produce un resultado consistente: la activación de regiones occipito-temporales en respuesta a la mirada (Callejas et al., 2014; Engell et al., 2010; Greene et al., 2009; Hietanen et al., 2006). Sin embargo, aún se necesita más investigación para aclarar si las redes neurales son íntegramente iguales o existen diferencias en el procesamiento neural entre ambas señales.

Si tuviésemos que describir un mecanismo neural para la orientación de la mirada, este implicaría inicialmente la participación de la red de atención ventral, procesando automáticamente las señales de la mirada. No obstante, esta respuesta a la orientación inicialmente automática podría ser controlada en función de las demandas de la tarea y el contexto por regiones de la red de atención dorsal.

De hecho estudios con electroencefalografía en los que se estudia el curso temporal de la respuesta cerebral frente a la orientación desencadenada por señales de flechas y miradas, muestran cómo los cambios automáticos de la atención ocurren en los componentes tempranos y es en componentes tardíos donde podrían encontrarse ciertas diferencias (Brignani et al., 2009; Uono et al., 2014). No obstante, al igual que en la literatura anterior aún no hay un consenso sobre cómo actúan ambas señales por lo que esta idea debe tomarse con cautela. Aunque sería interesante describir a nivel electrofisiológico los datos de la literatura que concierne a la orientación desencadenada por señales de flechas y miradas con paradigmas cuantitativos, esto se alejaría de los objetivos del presente trabajo.

3. 3 Correlatos neurales entre flechas y miradas, como estímulos objetivos

Es posible que los resultados inconclusos acerca de los mecanismos neurales implicados en la orientación atencional desencadenada por señales sociales y no sociales, tengan que ver con las características de los paradigmas utilizados para su propio estudio. Como hemos explorado en el Capítulo 2 de este trabajo, el uso de paradigmas cuantitativos como las tareas clásicas de orientación atencional o gaze-cueing parecen no ser adecuadas para identificar mecanismos diferenciales asociados al procesamiento de cada señal. De hecho, a nivel comportamental los efectos de orientación son comparables entre ambas señales (Chacón-Candia, Román-Caballero, et al., 2023), incluso en estudios donde se exploran las bases neurales (Callejas et al., 2014; Joseph et al., 2015).

Por ello, se hace imprescindible explorar otro tipo de paradigmas que busquen diferencias cualitativas tanto a nivel comportamental como neural, con lo que el objetivo sería estudiar cómo cada señal o estímulo desencadena el cambio atencional, en vez de comparar la magnitud de la orientación. Como se describió en el Capítulo 2, un paradigma que recientemente ha mostrado claras diferencias cualitativas entre la orientación atencional de ambos estímulos, es el paradigma de interferencia espacial (Marotta et al., 2018a) con el que se encuentran efectos de congruencia opuestos entre flechas y miradas. En un estudio reciente Marotta y colaboradores (2019) registraron la actividad cerebral con un encefalograma (EEG) de alta densidad mientras los participantes realizaban la tarea de interferencia espacial con la mirada y las flechas como estímulos objetivos, a los que debían responder, discriminando la dirección a la que miraban o apuntaban los estímulos. El objetivo del estudio fue comparar el procesamiento del conflicto espacial desencadenado por los estímulos de la mirada y de las flechas. Los resultados comportamentales mostraron efectos de congruencia clásica con las señales de las flechas y un efecto de congruencia revertida con la mirada, acorde con el estudio original (Marotta et al., 2018a). Los datos electrofisiológicos mostraron, por un lado, modulaciones similares en los efectos de congruencia de ambos estímulos (flechas y mirada) en los componentes tempranos (P1, N1 y N170), relacionados con las primeras etapas del procesamiento. Por otro lado, encontraron diferencias entre ambos estímulos en los componentes tardíos (N2 y P3). Los autores concluyeron que existen mecanismos similares entre flechas y miradas en las etapas iniciales del procesamiento perceptual y atencional de los estímulos. Sin embargo, existen también mecanismos diferentes entre ambos estímulos, representados en los componentes tardíos, implicados en el control cognitivo y la generación de respuesta.

Este es el primer estudio que explora la actividad cerebral durante la ejecución del paradigma de interferencia espacial, el cual utilizaremos durante las series experimentales de las que está compuesta esta tesis.

MOTIVATION AND AIMS

CHAPTER 4. Motivation, aims and overview of research

4.1 Motivation

In recent decades, there has been increasing research on social cognition and interest in understanding how we relate to our conspecifics (Capozzi & Ristic, 2018; Schurz et al., 2021). While the goal is to understand the emotions, intentions and actions of others to act towards and with them in social contexts (De Jaegher et al., 2010) this requires the engagement of different types of social cognition processes. These range from lower order social attention processes, such as gaze perception and shared attention, to more complex processes related to the theory of mind or empathy (Schurz et al., 2021; Stephenson et al., 2021).

Detecting and processing the direction of others' gaze and acting accordingly have been crucial to our individual and collective development (Emery, 2000). The morphological evolution of the human eye (Kobayashi & Kohshima, 1997), the preference and ability of newborns to attend to faces and gaze (Farroni et al., 2005), and the automaticity of following the gaze of others, make gaze a unique stimulus. The direction of others' gaze has great social significance and special status as an attentional cue, causing us to shift the focus of our attention to the exact location where others are attending (Birmingham & Kingstone, 2009).

Furthermore, gaze processing requires the joint involvement of neural mechanisms that underlie the so-called 'social brain' (Hadders-Algra, 2022; Nummenmaa & Calder, 2009); such as the temporo-occipital cortex (fusiform gyrus), the anterior and posterior superior temporal sulcus (STS), the superior temporal gyrus (STG), the orbitofrontal and medial prefrontal cortex, and the amygdala (Carlin & Calder, 2013; Itier & Batty, 2009; Senju & Johnson, 2009). Functional MRI studies suggest the involvement of the parietal cortex in gaze perception, specifically the superior intraparietal sulcus and the temporo-parietal conjunction, reflecting the involvement of the attentional system in encoding the spatial direction of another person's gaze and orienting attention in that direction (Itier & Batty, 2009; Nummenmaa & Calder, 2009).

Taking all evidence together, several researchers have proposed that attention to gaze may represent a unique attentional process reflecting the functioning of a specialised cognitive and neural mechanism (S. Baron-Cohen, 1995; Emery, 2000; Farroni et al., 2002)

To study the mechanisms of gaze-triggered attentional orienting, variants of Posner's cue paradigm (Gaze-cueing by Friesen & Kingstone (1998)) have been used to compare the attentional orienting of gaze to other evolutionarily irrelevant or non-social stimuli such as arrows. Both stimuli share the ability to communicate directional information, although arrows do not have the evolutionary and social significance of gaze. Most studies have either found no differences between the two types of cues or have found subtle differences (Birmingham & Kingstone, 2009), leading some authors (Galfano et al., 2012; Heyes, 2014; Santiesteban et al., 2014) to propose that gaze attentional effects are at least partially driven by a domain-general attentional process. Indeed, a recent comprehensive meta-analysis has shown no quantitative differences in attentional orienting effects between gaze and arrow cues using the gaze-cueing paradigm (Chacón-Candia, Román-Caballero, et al., 2023). According to Birmingham & Kingstone (2009), the gaze-cueing paradigm may not capture critical aspects of the gaze that distinguish it from other directional but non-social stimuli, such as arrows.

In fact, using other paradigms focused on studying how attention is oriented between the two cues (gaze and arrows) rather than on the magnitude of the effect, qualitative differences are found between the attentional orientation effects between arrows and gazes (Cañadas & Lupiáñez, 2012; Chacón-Candia, Lupiáñez, et al., 2023; Dodd et al., 2012; Gregory & Jackson, 2017; Marotta et al., 2012, 2018a).

In this line, the spatial interference paradigm has recently been used to dissociate the attentional effects of arrows and eye-gaze (Cañadas & Lupiáñez, 2012; Marotta et al., 2018). In this paradigm, participants have to discriminate the direction of the targets (arrows or gaze) unpredictably appearing to the left or right of the fixation point. Consistent with a spatial interference effect (Lu & Proctor, 1995; Lupiáñez & Funes, 2005) arrows elicited faster responses when their direction was congruent with their position (e.g., a left-pointing arrow presented to the left; standard spatial congruency effect; SCE), whereas gaze stimuli produced faster reaction times (RTs) when they were incongruent (e.g., a left looking gaze stimulus presented to the right; Reversed Congruency Effect; RCE). These opposite congruency effects have been widely replicated (Ishikawa et al., 2021; S. Jones, 2015; Marotta et al., 2018a, 2019b; Román-Caballero et al., 2021b; Torres-Marín et al., 2017). Although some explanations have been proposed to explain the opposite congruency effect between gaze and arrows with the spatial interference paradigm, the mechanisms underlying these dissociations are unknown. Therefore, this doctoral thesis aims to shed light on the common and differential mechanisms underlying the standard congruency effect (SCE) and reverse congruency effect

(RCE) elicited by arrows and gaze, respectively. Our behavioural and neuroimaging data aim at contributing to the study of social attention.

4.2 Aims and overview of research

This doctoral thesis aims further to study the cognitive and neural processes underlying social attention, particularly the attentional mechanisms triggered by social stimuli, such as gaze, by directly comparing them with other on-social stimuli, such as arrows. To address this goal, we used the spatial interference paradigm that had shown qualitative differences in the spatial congruency effect between gaze and arrows when both stimuli were used as targets.

We conducted three studies to respond to this general objective, each of them attempting to respond to the general aim through other specific objectives[1].

The first study (Chapter 5) investigated the nature of the attentional processes underlying the dissociation in spatial congruency effects between social and non-social stimuli. Specifically, to determine the nature of the attentional processes underlying the congruency effect and RCE observed with non-social and social stimuli, respectively. Previous studies (Cañadas & Lupiáñez, 2012; Marotta et al., 2018a, 2019b) have shown an opposite congruency effect between

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[1] Note that the chapters describing the experimental studies consist of research papers that have been published or are in the process of being published in indexed journals. Therefore, there might be a certain overlap in the introduction and discussion of the different chapters and with the introduction and general discussion of this doctoral thesis.

arrows and gaze, in the spatial interference task, when using an inter-block design in which stimuli (gaze and arrows) are presented in separate blocks. This result might be determined by the different attentional strategies adopted by the participants related to the task set. So the first aim of this study was to replicate the previous results using an intra-block. Concurrently, this type of design allowed us to study how the spatial conflict was resolved on a trial-by-trial basis. Previous experience with conflict modulates the congruency effect, reducing the congruency effect on trials preceded by an incongruent trial (Gratton et al., 1992). This phenomenon, known as the congruency sequence effect (CSE), indicates how people adapt their behaviour in response to conflict. Therefore, the second aim of this work is to study the sequential effects of conflict between social and non-social stimuli (arrow-gaze, gaze-arrow, gaze-gaze, arrow-arrow). Exploring the generalisation of CSE between stimulus types will allow us to investigate shared and dissociable conflict resolution mechanisms between both types of stimuli. Two possible scenarios related to the sequential conflict effects generated by the arrow and gaze stimuli were hypothesised. In the first scenario, the mechanisms underlying the congruency effects were considered to be stimulus-specific, reflecting independent mechanisms or different types of conflict, which would result in the absence of CSE between stimuli (Arrow-Gaze or Gaze-Arrow). In the second scenario, it was considered that the mechanisms underlying the congruency effects could generalise across stimuli, generating opposite CSE, reflecting the opposite nature of the congruency effects for each stimulus. However, neither of these two scenarios was fulfilled during the study, and the pattern of data from the first experiment led to the proposal of a third scenario, which was tested and replicated within the same study.

Based on the outcome of study one, it was shown that the arrow and gaze stimuli shared a spatial interference mechanism responsible for the CSE. We also hypothesised the existence of an additional, possibly social, mechanism involved in responding to gaze stimuli. This mechanism will be responsible for the RCE. **The second study (Chapter 6) of this thesis is related to the study of the social component involved in the RCE. The objective of the second study was to test whether the eye contact hypothesis is responsible for the reversed congruency effect that occurs with gaze stimuli.** The eye contact hypothesis, one of the most widely used hypotheses to explain this effect up to that time, was tested. The first studies on the RCE (Cañadas & Lupiáñez, 2012; Marotta et al., 2018a, 2019b) explained this specific effect of gaze as an eye contact effect that would occur on incongruent trials. These authors (Cañadas & Lupiáñez, 2012; Marotta et al., 2018a) suggested that participants may perceive the gaze on incongruent trials as directed towards themselves, as a possible initiation of eye contact. This would facilitate their processing compared to the congruent condition where the participant would be confronted with an averted gaze. According to the literature (Sato et al., 2007; Stein et al., 2011; Xu et al., 2018), direct gaze captures attention quickly and even when its processing is implicit or unconscious. Motivated by this fact, we modified the stimuli by manipulating an orthogonal variable to stimulus direction and position, such as colour, in order to create two versions of the task: one implicit (discriminating colour) and the other explicit (discriminating direction). We hypothesized that if the eye contact effect is responsible for the RCE with gaze, it should be observed in both the explicit and implicit task since the eye contact effect would always occur, even when participants do not pay attention to the direction of the stimuli or the processing of the direction of the stimuli is incidental or implicit. For arrows, we expect a standard congruency effect in the explicit task and no congruency effect in the implicit task, because there was no interference between the relevant and irrelevant dimensions. Additionally, this version of the task allowed us to test whether the motor component involved in the manual response to the task could be involved in the differences observed between both stimuli and both versions of the task.

The third specific objective of this doctoral thesis is developed in the third study (Chapter 7), in which we explore the neural mechanisms underlying the differences observed in the congruency effect between arrows and gaze. For this purpose, we adapted the original paradigm for an fMRI design. To explore their shared and dissociable underlying mechanisms, we compared brain activations and co-activations for congruent and incongruent arrow and gaze stimuli. The fMRI technique will allow us to see shared activations (Incongruent > Congruent), which are expected in the arrows, and perhaps also in the gaze, related to general domain attentional effect, and activations (Congruent > incongruent) that are only expected to be found in the gaze (gaze-specific effect that we would not find with the arrows). We hypothesised that frontal and parietal region associated with conflict resolution and spatial orientation would show similar congruency effects, while ventral regions (STS and Right TPJ) and regions involved in face processing and gaze direction (IOG and FG) would show different patterns between arrows and gaze in the congruency effect.

The thesis concludes with General Discussion (Chapter 8), in which we analyse, integrate and interpret the findings of the present doctoral dissertation according to the current literature. We first summarise all our findings from the doctoral thesis. Secondly, we discuss the main results of the three studies in relation to the literature to explain which shared mechanisms are involved in the processing of arrows and gaze, and which mechanisms are different and stimulus-specific. Finally, we provide future lines of study for further research on this topic.

In summary, in this doctoral thesis, we use a behavioural approach (first and second studies) and a neural approach (third study) to answer the general objective, allowing us to better understand what cognitive and neural processes might underlie the qualitative differences between arrows and gaze using the spatial interference paradigm.

EXPERIMENTAL SERIES

Chapter 5

First Study

Gaze Elicits Social and NonSocial Attentional Orienting: An Interplay of Shared and Unique Conflict Processing Mechanisms

The content of this chapter has been published as:

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

*These two authors have contributed equally to this work

5.1 Abstract

Subtle to no attentional differences have been broadly observed when using gaze and arrows as orienting cues. However, recent studies have found opposite effects when they are used as targets in spatial interference tasks, with arrows eliciting faster responses when their position is congruent with the indicated direction and gaze producing faster responses in incongruent conditions. In two preregistered experiments aimed at exploring the mechanisms supporting these findings, we examined whether the congruency sequence effects (CSE) elicited by gaze and arrows generalized from one stimulus to another, using an intra-block design where the type of stimuli was manipulated on a trial-by-trial basis. Typical CSE were observed for arrows, with a decrease of congruency effects after incongruent trials, and reversed CSE for gaze, with an increased inversion of congruency effects after incongruent trials. Both patterns occurred independently of the preceding type of target, showing that congruency effects can decrease after positive outcomes (e.g., arrow trials following an incongruent gaze trial), and generalized across different non-social and social stimuli as shown in a third experiment. These results are consistent with the coexistence of a shared spatial interference component between gaze and arrow trials, potentially responsible for the CSE obtained in switching target trials, and an additional social dimension, exclusively engaged in gaze trials.

Keywords: congruency sequence effect, gaze, reversed congruency, sequential effect, social attention

Public Significance Statement

- This study suggests that the direction of gaze offers valuable information to overcome other non-social sources of conflict. Lateralized gaze, seems to produce a spatial interference effect, shared with non-social stimuli like arrows, and a specific social conflict effect.
- When the observer's and observed gaze meet in the center of the task area, a possible joint attention effect might facilitate faster and more accurate processing of the direction of the gaze. Whereas a gaze looking outwards of the task area leads to less accurate and slower responses, perhaps due to a process of "joint distraction".
- These findings may be useful in applications to populations with difficulties in the identification and interpretation of social markers.
- Priming of specific cognitive control processes, rather than relative efficiency of processing, seems to underlie congruency sequence effects.

5.2 Introduction

Our gaze, a key protagonist of social interactions, allows us to acquire information from the environment and simultaneously signal back towards it (Jarick & Kingstone, 2015). Regarding this second property, the gaze can be considered a stimulus in itself, with a unique morphology that we are prepared to recognize from an early age (Batki et al., 2000). The human sclera (white area surrounding the darker iris) is significantly more exposed compared to other species', reflecting how our gaze has evolved sacrificing adaptation to camouflage from predators in order to gain increased gaze signal (Kobayashi & Kohshima, 1997). Over time, we have developed rather standard responses to some of these "signals". For example, experiencing eye contact generally leads to increased arousal (J. K. Hietanen et al., 2008), and we tend to automatically follow the direction of others' averted gaze (Emery, 2000). Others' gaze even shapes our interactions with the environment, as objects that are being looked at by someone else are preferred over objects that are not, which does not occur with other non-social pointers, such as arrows (Bayliss et al., 2006). Furthermore, the gaze can act as a powerful distractor; as, for example, spatial interference increases when a pair of eyes is included peripherally in a Stroop Task (Conty et al., 2010).

Given the importance of gaze, whether it interacts differently than non-social pointers with visual attention has been thoroughly researched, mainly with cueing paradigms, wherein attention is led (or misled) through cues (e.g., arrows or gaze) to the location of a given target (Jason Tipples, 2008). However, most findings support that gaze and arrows produce the same cueing effect and thus, that the same mechanisms underlie their processing (Brignani et al., 2009; Jason Tipples, 2008); with only few studies actually reporting some differences. For example, without affecting response times, gaze-cues improve the encoding of task-relevant information in working memory, compared to arrow-cues (Gregory & Jackson, 2017). Additionally, gaze cues selectively orient attention towards a specific location within the cued target object (i.e., the specific looked at location), while arrow cues shift attention towards the object as a whole (Marotta et al., 2012). Furthermore, the status attributed to the faces providing cues influences their impact, as Chinese participants show gaze-cueing effects for White but not Asian faces, and White participants, for faces of their own but not of Black ethnicity (Zhang et al., 2020). These findings may indicate there are actual qualitative differences between social and non-social pointers, which the cueing paradigm is not fit to fully identify. In other words, the general intuition that eyes are special seems plausible, but the cueing paradigm may not be measuring what makes eyes distinct from arrows. A different approach to studying whether the attentional mechanisms of social stimuli are different from those of non-social stimuli is to explore their qualitatively different effects. In particular, finding opposite effects between the attentional mechanisms engaged by gaze and arrow stimuli would support the idea that they can work independently of each other.

In this sense, perhaps the clearest evidence for functionally dissociable attentional mechanisms between social and non-social stimuli was observed by Cañadas and Lupiáñez, (2012), who reported an opposite modulation, within the same experiment, between the spatial interference effects induced by these two types of stimuli. They used a Spatial Stroop Task (Lu & Proctor, 1995), an interference paradigm where a stimulus, usually an arrow, is presented on either side (left/right) of the screen, pointing either left or right. The arrow's location (i.e., irrelevant feature) may interfere with the arrow's pointing direction (i.e., relevant feature), generating a conflict that ought to be resolved to respond correctly. This conflict, generated on incongruent trials, is generally reflected in larger reaction times (RTs) and higher error rates than on congruent trials, their difference being known as *congruency effect.* Comparing social vs. non-social stimuli with the above described spatial interference task, Cañadas and Lupiáñez (2012), obtained a complete dissociation between them. With non-social stimuli (arrows), a standard *congruency effect* was found. Whereas, surprisingly, with social stimuli (full faces and cropped eyes), slower RTs and more errors were observed for congruent vs. incongruent trials. This effect observed on social stimuli, referred to by the authors as *reversed congruency effect* (Cañadas & Lupiáñez, 2012), has been repeatedly replicated since then (Aranda-Martín et al., 2022; Edwards et al., 2020; Ishikawa et al., 2021; Jones, 2015; Marotta et al., 2018, 2019; Narganes-Pineda et al., 2022; Román-Caballero et al., 2021a, 2021b; Torres-Marín et al., 2017). Recently, the same pattern of standard and reversed congruency effects, for arrows and gaze, respectively, has been replicated through a within-participant counterbalanced blocked design (Marotta et al., 2018b). Moreover, the reversed congruency effect is more pronounced when embedding the gaze in faces displaying emotions such as happiness or anger, than for neutral faces (S. Jones, 2015), further supporting the idea that eyes represent unique attentional stimuli.

In the present study, we replicated and critically extended these findings, comparing the effects produced by arrow and gaze stimuli presented randomly within the same experimental block. This manipulation prevents participants from adopting a specific "task set" for each type of stimulus, and more importantly, it allows studying sequential effects between non-social and social stimuli (i.e., arrow-gaze/gaze-arrow) or between the same stimulus type (i.e., arrow-arrow/gaze-gaze).

In this regard, it is known that the previous experience of conflict modulates the congruency effect, as it diminishes in trials immediately preceded by an incongruent one (Gratton et al., 1992). In other words, the detection of conflict on incongruent trials creates the need to implement control to reduce interference. Consequently, when the following trial is also incongruent, the cognitive control system is already activated and prepared to solve the new conflict (incongruent trials), leading to a reduced congruency effect. This phenomenon, labeled as *Congruency Sequence Effect* (CSE), is taken as an indicator of how people adapt their behavior in response to a conflict, and it is usually studied by means of a conflict task; like the flanker, Simon, or Stroop Task (for a review on CSE, see Braem et al., 2014). The nature of CSE and, consequently, the understanding of such a trial-by-trial process could shed new light on how cognitive systems exert continuous control over allegedly automatic response tendencies. According to accounts of conflict (Botvinick et al., 2001) and conflict monitoring (Botvinick, 2007), cognitive control is applied generally, regardless of the specific features that triggered past experiences of conflict or negative outcomes. In contrast, a recent literature review concluded that conflict-driven control is conflict-specific (Egner, 2008). Indeed, Funes et al., (2010) used a direction discrimination task that produced two types of spatial conflict (Stroop and Simon), obtaining clear CSE when the same type of conflict was repeated over successive trials (i.e., they were observed from Simon to Simon and from Stroop to Stroop trials), but no CSE when conflict types alternated between trials, referred to as cross-conflict effects (i.e., they were not observed from Simon to Stroop or from Stroop to Simon trials). Similar results have been observed over multiple studies (Egner et al., 2007; Kiesel et al., 2007; Verbruggen et al., 2005; Wendt et al., 2006), strongly suggesting that CSE are conflict-type specific. Thus, testing whether CSE can be obtained in consecutive trials across different conditions, such as spatial interference from social and non-social trials (i.e., gaze and arrows), could be used to test whether such conditions share common processing mechanisms in conflict resolution.

We initially considered two possible outcome scenarios concerning cross-conflict sequential effects between arrows and gaze (i.e., when conflict types alternated between trials), depending on whether their underlying control mechanisms were specific or general. The first scenario considered the possibility that the processes underlying the congruency effects elicited by arrows vs. gaze reflect independent mechanisms or different types of conflict, in hand with the above-reviewed evidence supporting the conflict specificity of CSE (Funes et al., 2010). Thus, this *first* scenario contemplates a complete *absence of sequential effects between cross-conflict trials* (i.e., no observed CSE in arrow-gaze trials, or vice versa).

On the other hand, a second scenario considered that effects of cognitive control could generalize between arrows and gaze, as well as the opposing nature of congruency effects for each stimulus (standard congruency effects for arrow trials and reversed congruency effects for gaze trials), where the optimal level of performance is provoked by opposing conditions for each stimulus (congruent trials for arrows and incongruent ones for gaze). Therefore, applying the strategies used for resolving the conflict for one type of stimulus in one trial, would hinder resolving the conflict of a following trial with the other stimulus. Thus, cross-conflict trials could lead to opposite CSE, in this *second* possible scenario that could predict *reversed CSE for cross-conflict trials*.

Presenting arrows and gaze in a spatial interference task through a within-block design allowed us to: (a) assess whether the reversed congruency effects observed for gaze stimuli are provoked by the exposure to the stimulus itself, rather than by participants adopting a different global strategy for blocks exclusively containing these stimuli; and more importantly (b) explore the Congruency Sequence Effect (CSE) of responding to arrows compared to gaze, providing insight into the possible mechanisms underlying the reversed congruency effect observed for gaze stimuli, depending on the scenario that the results conformed to.

Surprisingly, the results of the first experiment did not conform to either of the two hypothesized scenarios, revealing a third pattern of behavior that was put to test and replicated in two additional experiments.

5.3 EXPERIMENT 1

In Experiment 1, we aimed to replicate the findings of Marotta et al. (2018) in the context of a within-block randomized design and to further explore sequential effects. We proposed the following preregistered hypotheses (Hemmerich et al., 2018; osf.io/fw8dn): (a) we expected to replicate the standard congruency effects observed for arrow stimuli randomly manipulated within the same block of trials, with arrows eliciting faster RTs when their direction is congruent with their spatial position; (b) we expected to find reversed congruency effects for gaze trials, with gaze producing faster RTs when its position is opposite to its gazing direction; (c) we expected to observe CSE for both gaze and arrows after repetitions of the same target type (i.e., gaze-gaze or arrow-arrow); and (d) in absence of specific predictions for cross-conflict trials (e.g., arrow-gaze), we expected that the resulting data could provide critical information both about the nature of sequential effects and the mechanisms involved in each of these conflict conditions.

Method

Participants

A total of 36 healthy volunteers (27 women, mean age = 21.72, *SD* = 2.71, range = 18-31) participated in Experiment 1. A sensitivity power analysis (performed with G*Power; Faul et al., 2007) assuming an alpha criterion of 0.05 and a power criterion of 0.80 revealed that, with a sample of 36 participants, the smallest effect size that could have been detected was $\eta_p^2 = .039$ for the Target Type × Congruency interaction, and $\eta_p^2 = .025$ for the critical three-way interaction. All participants were naïve students from the University of Granada, reported normal or corrected to normal visual acuity, and participated in the experiment for course credits. The experiment was conducted following the ethical standards of the 1964 Declaration of Helsinki (last update: Seoul, 2008), integrated into a larger research project, approved by the Ethical Committee of the University of Granada (175/CEIH/2017).

Material, apparatus, and stimuli

We used the same general procedure and stimuli as Marotta et al. (2018), as shown in Figure 1. The presentation and timing of stimuli, as well as data collection, were designed and run on a standard Pentium 4 PC, using E-Prime 2.0 software (Schneider et al., 2002). The stimuli white upright rectangles containing two black arrows (non-social stimuli) or two eyes (social stimuli) of an approximate size of 5.5 × 1 cm were presented on a 17'' widescreen monitor with a 1024 × 768-pixel resolution. The eyes were cropped from the original faces (from the NimStim Set of Facial Expressions; https://danlab.psychology.columbia.edu/content/nimstim-set-facial-expressions) with Adobe Photoshop CS.

Procedure

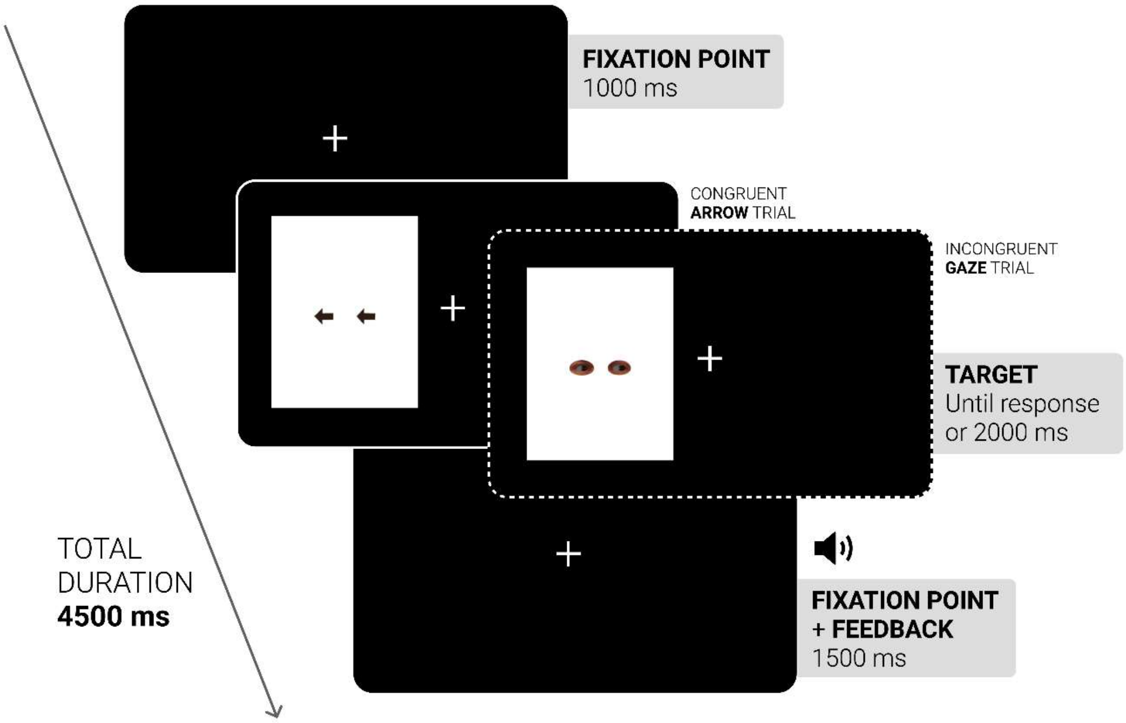
Participants were seated in front of a computer screen (at approximately 60 cm) in a faintly lit room and instructed to fixate on a cross shown in the center of the screen. After this, a pair of eyes or arrows appeared either to the left or right of the fixation point at a horizontal distance of 10.5 cm (from the stimulus' center). Participants were instructed to determine as fast and accurately as possible where the target was pointing/looking towards, independently of its location, and to respond with spatially corresponding keys, the "Z" key for stimuli pointing/looking to the left and the "M" key for those pointing/looking to the right. This design leads to spatially congruent trials (e.g., targets pointing to the right, requiring a response on the right and presented on the right side of the screen), and spatially incongruent trials (e.g., targets pointing to the right, requiring a response on the right, but presented on the left side of the screen).

The maximum duration of a trial was 4500 ms, presenting the fixation point for 1000 ms, the target for a maximum of 2000 ms (as it disappeared upon the participant's response), and the end fixation point for 1500 ms; as shown in Figure 1.

A practice block of 15 trials, not further analyzed, was presented after instructions to ensure that participants understood the task. Auditory feedback was provided during practice and experimental trials for incorrect keypresses, consisting of a 220-Hz tone presented during the second fixation screen, and visual feedback was provided when no response was detected on either of the keys. The experimental task included 256 trials divided into 4 blocks with a short break in between.

Figure 1.

Procedure of Experiment 1, featuring a congruent arrow trial (arrow direction and location match) in the main row, and an incongruent gaze trial (gaze direction and location are opposite) in the overlapped screen.



Note. Only one or the other was presented on each trial. Eye stimuli modified from the NimStim Set of Facial Expressions.

Design

The core experimental design was a two-factor repeated measures design (ANOVA) with Target Category (2, social and non-social), and Congruency (2, congruent and incongruent) as two within-participant factors, with 64 observations per experimental condition. Additionally, sequential effects were recorded offline by creating two additional variables: Previous Congruency (2, congruent and incongruent) and Previous Target Category (2, same and different). Considering all four variables, there was an average of 15,75 observations per experimental condition, ranging from 7 to 27.

The combination of previous and current congruency led to four kinds of transitions between trials: from congruent to congruent trial (CC), from congruent to incongruent (CI), from incongruent to congruent (IC), and incongruent to incongruent (II). The impact of these transitions on performance can be studied in four scenarios: two for repeating target types (either non-social or social) and two for transitioning from social trials to non-social trials, or vice versa.

Results

As in Marotta et al. (2018), mean RTs and error rates (shown in Table 1) were calculated for each condition. In Experiment 1, the results from one participant were eliminated, since their responses during the task were not correctly recorded. Following the preregistered plan of analyses, we excluded the first trial of each block (1.56% of the remaining trials) in order to analyze CSE, as well as error trials (2.44%), trials following an error (2.40%), and trials with RTs above 1300 ms (0.66%) or below 200 ms (0.20%), following the same data filtering as Cañadas and Lupiáñez (2012) and Marotta et al. (2018).

Table 1.

Mean reaction times (RT) and error rates, and their corresponding standard deviations (SD) for sequential trials of Experiment 1.

TC	Pre-TC	Pre-CC	C	RT Mean	RT *SD*	Error rates Mean	Error rates *SD*
Non-social (Arrow)	Different	C	C	541	*70*	0.002	*0.012*
			I	564	*93*	0.013	*0.030*
		I	C	551	*62*	0.002	*0.011*
			I	552	*86*	0.002	*0.014*
	Same	C	C	506	*69*	0.004	*0.024*
			I	555	*90*	0.012	*0.028*
		I	C	550	*73*	0.010	*0.033*
			I	543	*94*	0.006	*0.019*
Social (Gaze)	Different	C	C	645	*85*	0.031	*0.058*
			I	648	*86*	0.058	*0.101*
		I	C	668	*84*	0.058	*0.094*
			I	633	*90*	0.022	*0.044*
	Same	C	C	633	*85*	0.022	*0.046*
			I	642	*93*	0.036	*0.066*
		I	C	662	*79*	0.066	*0.108*
			I	620	*99*	0.027	*0.047*

Note: TC (Target Category of current trial), Pre-TC (Previous Target Category, either same or different), Pre-C (Previous Congruency, either congruent (C) or incongruent (I)), C (congruency of the current trial).

Reaction Time

The overall ANOVA conducted on RTs with Target Category, Previous Target Category, Congruency, and Previous Congruency as repeated measures revealed a main effect of Target Category, $F(1, 34) = 248.76$, $p < .001$, $\eta_p{}^2 = 0.88$, with significantly faster RTs for non-social than social targets (545 ms vs. 643 ms). Whilst there was no main effect of Congruency ($F < 1$), there was a significant Target Category × Congruency interaction, $F(1, 34) = 14.35$, $p < .001$, $\eta_p{}^2 = 0.30$, which reflected the expected standard and reversed congruency effects for non-social (i.e., arrows) and social targets (i.e., gaze) respectively. Thus, on non-social (arrow) trials, RTs were faster for congruent (537 ms) than incongruent trials (554 ms), $F(1, 34) = 7.22$, $p = .011$, $\eta_p{}^2 = 0.18$, whereas on social (gaze) trials, RTs were faster for incongruent (636 ms) than for congruent trials (652 ms), $F(1, 34) = 5.42$, $p = .026$, $\eta_p{}^2 = 0.14$.

Regarding the effect of the preceding trial, the ANOVA revealed a main effect of Previous Target Category, $F(1, 34) = 13.91$, $p < .001$, $\eta_p{}^2 = 0.29$, as target type repetitions led to faster RTs (589 ms) than alternations (600 ms). More importantly, the interaction between Congruency and Previous Congruency (reflecting CSE), was significant, $F(1, 34) = 44.83$, $p < 001$, $\eta_p{}^2 = 0.57$; and, furthermore, modulated by Previous Target Category, $F(1, 34) = 6.98$, $p = .012$, $\eta_p{}^2 = 0.17$.

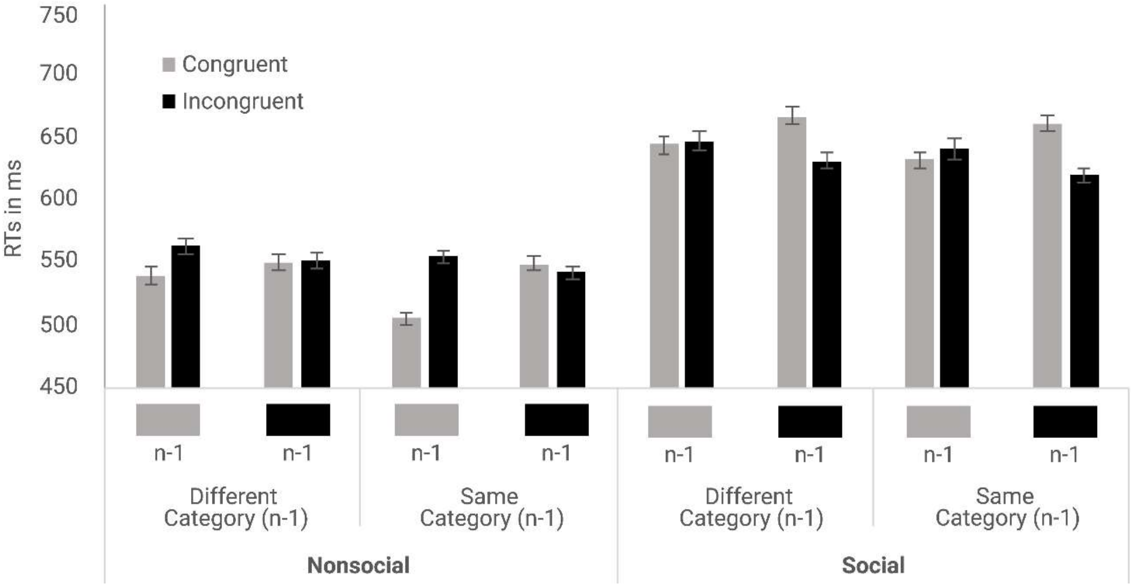
To further explore the type of CSE that arose in each condition, we conducted two separate ANOVAs, one for each succession type (same or different previous target category). The ANOVA conducted for the *same previous target category* showed a significant two-way interaction between Congruency and Previous Congruency, $F(1, 34) = 53.94$, $p < 001$, $\eta_p{}^2 = 0.61$, that was not modulated by Target Category ($F < 1$). Thus, as hypothesized, the CSE was significant both for consecutive non-social trials (i.e., arrow-arrow), $F(1, 34) = 44.51$, $p < .001$, $\eta_p^2 = 0.57$, and for consecutive social trials (i.e., gaze-gaze), $F(1, 34) = 26.91$, $p < .001$, $\eta_p^2 = 0.44$. For non-social trials, larger differences in favor of congruent trials arose after congruent trials (49 ms, $p < .001$), whereas an opposite non-significant effect was observed after incongruent trials (-7 ms, $p = .417$). In contrast, for social trials, showing a negative congruency effect, the effect became more favorable to incongruent trials when they followed another incongruent trial (-42 ms, $p < .001$), whereas an opposite non-significant effect was observed after congruent trials (9 ms, $p = .349$).

More importantly, the ANOVA conducted to assess CSE on trials following a *different previous target category* also revealed a significant Congruency × Previous Congruency interaction, $F(1, 34) = 14.03$, $p < 001$, $\eta_p^2 = .29$, not modulated by Target Category ($F < 1$). Specific analyses conducted on CSE in each transition type showed a significant interaction for social–non-social (i.e., gaze-arrow) successions, $F(1, 34) = 4.77$, $p = .036$, $\eta_p^2 = 0.12$, and non-social–social (i.e., arrow-gaze) successions, $F(1, 34) = 11.60$, $p = .002$, $\eta_p^2 = 0.25$. For nonsocial trials, differences in favor of congruent trials arose after congruent trials (23 ms, $p = .037$), which disappeared after incongruent trials (1 ms, $p = .846$). In contrast, for social trials, showing a negative congruency effect, the effect became more favorable to incongruent trials when they followed another incongruent trial (-36 ms, $p = .002$), which disappeared after congruent trials (3 ms, $p = .783$).

Thus, despite non-social and social trials producing opposite congruency effects, similar CSE were obtained for each target category, regardless of the nature of the preceding target category. Therefore, both incongruent non-social and incongruent social trials lead to reduced standard congruency effects in successive non-social trials, and to increased reversed congruency effects in successive social trials.

Figure 2.

Average RTs of Experiment 1 in response to either non-social or social targets, represented separately for congruent and incongruent trials, for trials preceded by a congruent or incongruent trial, and successions of different vs. the same target category.



Note. Error bars represent the Standard Error of the Mean (SEM) adjusted with Cousineau's method (2005) to eliminate between-participants' variability.

Error Rates

The error rates reflected the pattern observed in RTs, as shown in Table 1. The ANOVA revealed a main effect of Target Category, $F(1, 34) = 17.55$, $p < .001$, $\eta_p^2 = 0.34$, reflecting significantly lower error rates for non-social (.01) than social trials (.04). No other main effects yielded significant differences ($F < 1$). A significant Congruency × Previous Congruency interaction, $F(1, 34) = 10.96$, $p = .002$, $\eta_p^2 = 0.24$, reflected the expected pattern of CSE, and a three-way Congruency × Previous Congruency × Target Category interaction, $F(1, 34) = 6.26$, $p = .017$, $\eta_p^2 = 0.16$, indicated that CSE tended to be less pronounced for non-social than for social trials. This could be explained by a floor effect on error rates of non-social trials (consistently around .01).

Testing for the appearance of CSE patterns in two independent ANOVAs yielded significant Congruency × Previous Congruency interactions both for *same target category successions*, $F(1, 34) = 6.06$, $p = .019$, $\eta_p^2 = 0.15$, and *different target category successions*, $F(1, 34) = 11.47$, $p = .002$, $\eta_p^2 = 0.25$. Further analyses of CSE depending on succession type and target category, showed that for successions involving the same category of target, CSE were significant for social, $F(1, 34) = 4.93$, $p = .033$, $\eta_p^2 = 0.13$, but not for non-social targets, $F(1, 34) = 2.71$, $p = .109$, $\eta_p^2 = 0.07$. When alternating between target categories, CSE were also significant for non-social–social (i.e., arrow-gaze) successions, $F(1, 34) = 9.28$, $p = .004$, $\eta_p^2 = 0.21$, but not for social–non-social (i.e., gaze-arrow) successions, $F(1, 34) = 3.34$, $p = .077$, $\eta_p^2 = 0.09$. This pattern can be attributed to the aforementioned floor effects affecting non-social trials.

Discussion of Experiment 1

The results of this first experiment allowed us to reach five interim conclusions: (a) responding to the direction that two arrows are pointing to is faster and more accurate than responding to the looking direction of two eyes, (b) the effect of congruency between the relative position of a stimulus and its pointing direction is reversed for gaze compared to arrows, and this reversal does not depend on a global strategy adopted by participants when responding exclusively to one type of stimulus in a given block of trials; (c) standard CSE are observed for successions of arrow trials, with increased congruency effects after congruent trials; (d) reversed CSE are observed for successions of gaze trials, facilitating responses to incongruent gaze trials right after another incongruent gaze trial; and (e) rather surprisingly, no significant differences in CSEs were obtained regardless of the type of target presented on preceding trials, and therefore, regardless the experienced conflict (e.g., larger arrow congruency was observed after congruent arrows or congruent gaze, no matter whether they respectively produced faster responses, i.e., low conflict, or slower responses, i.e., high conflict).

These last results indicate that CSEs are driven by sharing the same type of spatial congruency rather than by the overall efficiency of previous performance, as predicted by models based on the evaluation of previous outcomes (Botvinick, 2007). Indeed, they may indicate that the driving force behind these sequential effects is the repetition of the same congruency component between successive trials rather than the relative efficiency of the response emitted in the previous trial. This aligns with the results of studies of electromyographic (EMG) activity during a Simon task, where reductions of the conflict effect following a conflict trial arose independently of whether the EMG registered an experience of conflict, in terms of the activation of the incorrect response (Burle et al., 2005).

Regarding our pre-registered predictions, the observed data pointed towards a third scenario instead of confirming one of the two possible outcome scenarios for cross-conflict sequential effects. On the one hand, standard CSE for arrow trials (independent of the previous target category), may reflect the existence of a spatial congruency component, common to arrows and gaze, responsible for facilitating the transfer between them. However, the reversed CSE observed in gaze trials (regardless of previous target category), could point towards the existence of a specific social component of "looking" that may impair responses to eyes gazing in the same direction of their position on the screen (i.e., congruent condition), or facilitate responses to the opposite direction (i.e., incongruent condition), thus counteracting the spatial congruency effect. This explanation of the observed pattern of results receives support from a recent electroencephalography (EEG) study that, using the same paradigm, observed similar modulations of early event-related potential components (ERP) by both gaze and arrow stimuli (P1, N1 and N170), but opposite modulations in later ERP components (N2 and P3) for each stimuli type (Marotta et al., 2019a).

To test the *a priori* prediction that presenting the social and non-social stimuli randomly interspersed within a block of trials would lead to *standard CSE for cross-conflict successions ending in arrow trials*, and to *reversed CSE for successions ending in gaze trials,* we considered it crucial to seek replication of these results through another experiment.

5.4 EXPERIMENT 2

Given the novelty of the research question and the unexpected results, we planned Experiment 2 with the main aim of replicating and confirming the previous results in the context of the following pre-registered hypotheses (Hemmerich et al., 2018; osf.io/r975q) expecting to find: (a) standard congruency effects for non-social (arrow) trials; (b) reversed congruency effects for social (gaze) trials; (c) standard CSE for non-social (arrow) trials; (d) reversed CSE for social (gaze) trials; and (e) replication of these stimulus-specific CSE for cross-conflict trials. This latter result would support the interpretation that social directional stimuli share a common source of spatial interference with non-social directional stimuli, producing CSE between them, whilst an added social feature, counteracting the spatial interference, would be ultimately responsible for the overall reversed congruency effect observed for gaze trials.

Method

To test the robustness of the phenomena observed in Experiment 1, we followed the same method, with only slight changes that were included to adapt the procedure for a prospective EEG study.

Participants

A new sample of 36 healthy volunteers participated in this experiment (33 women, mean age = 19.92, *SD* = 1.23, range = 18-23).

Material, apparatus, and stimuli

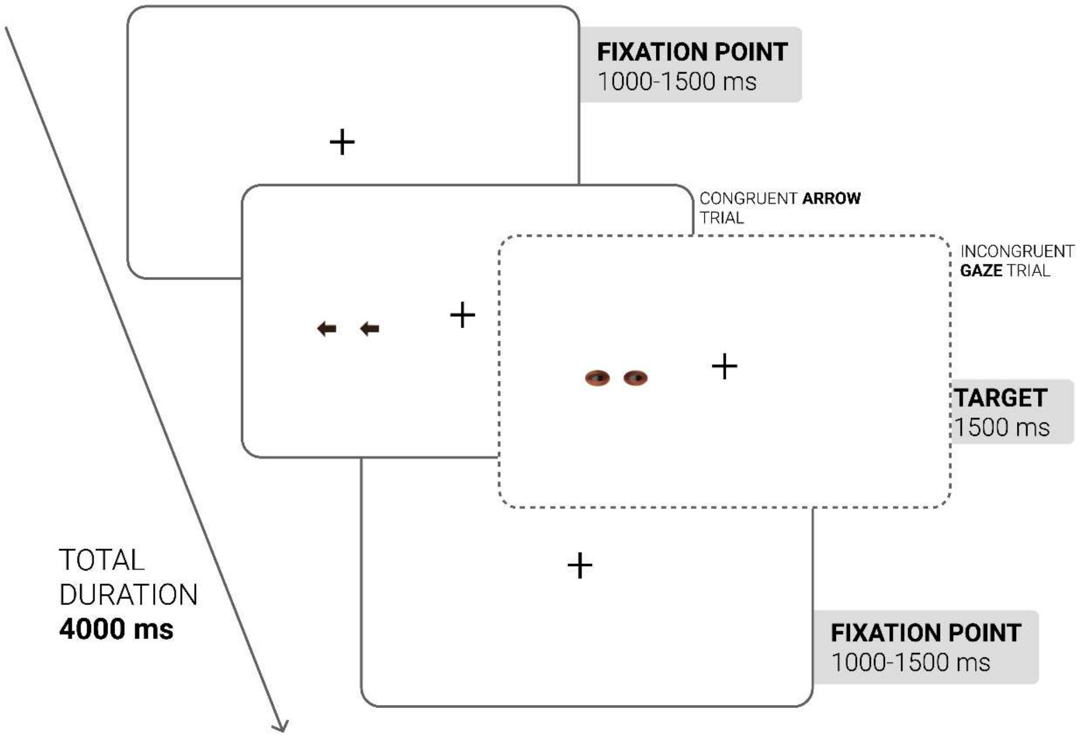
Unlike in Experiment 1, the targets were presented on a completely white background, and located at 43% of the Y-axis (from top to bottom), thus slightly higher than the central fixation point.

Procedure

Contrary to Experiment 1, to adapt the procedure for a future ERP study, the duration of the initial fixation display varied randomly between 1000-1500 ms, the target was presented for a fixed duration of 1500 ms (regardless of the participants' RT), whilst the duration of the fixation screen at the end also varied between 1000 and 1500 ms, compensating for the duration of the initial fixation display, so that each trial lasted 4000 ms, as depicted in Figure 3. During practice trials, we provided participants with the same feedback as in Experiment 1, which was, however, removed during the experiment itself.

Figure 3.

Procedure of Experiment 2, which mainly differed from the previous experiment in the screen background and the timing of the stimuli.



Note. Only arrows or eyes were presented on each trial. Eye stimuli modified from the NimStim Set of Facial Expressions

Design

The same design and analyses as in Experiment 1 were performed for Experiment 2. As in Experiment 1, the variables pertaining to previous trials were coded offline leading to the same four variables (Target Category, Congruency, Previous Target Category, and Previous Congruency), yielding an average of 15,75 observations per experimental condition, ranging from 7 to 25.

Results

Following the same filtering for Experiment 1 on mean RTs and error rates for each condition (shown in Table 2), data from 3 participants were excluded because no valid data were obtained during several blocks. For the remaining participants, we excluded the first trial of each block (1.56%), error trials (5.03%), trials following an error (4.97%), and trials with RTs above 1300 ms (0.59%) and below 200 ms (0.53%).

Table 2.
Mean reaction times (RT) and error rates, and their corresponding standard deviations (SD) for sequential trials of Experiment 2.

				RT		Error rates	
TC	Pre -TC	Pre -CC	C	Mean	*SD*	Mean	*SD*
Non-social (Arrows)	Different	C	C	529	*60*	0.004	*0.016*
			I	561	*65*	0.027	*0.057*
		I	C	550	*54*	0.010	*0.029*
			I	555	*65*	0.000	*0.000*
	Same	C	C	507	*62*	0.003	*0.015*
			I	553	*60*	0.031	*0.047*
		I	C	540	*53*	0.006	*0.021*
			I	530	*73*	0.007	*0.018*
Social (Gaze)	Different	C	C	688	*79*	0.077	*0.106*
			I	687	*70*	0.106	*0.105*
		I	C	722	*79*	0.101	*0.116*
			I	661	*70*	0.066	*0.082*
	Same	C	C	666	*81*	0.049	*0.076*
			I	682	*65*	0.104	*0.114*
		I	C	696	*70*	0.112	*0.114*
			I	642	*69*	0.050	*0.085*

Note: TC (Target Category of current trial), Pre-TC (Previous Target Category, either same or different), Pre-C (Previous Congruency, either congruent (C) or incongruent (I)), C (congruency of the current trial).

Reaction Time

The overall ANOVA conducted on RTs with Target Category (non-social and social), Previous Target Category (same and different), Congruency (congruent and incongruent), and Previous Congruency (congruent and incongruent) as repeated measures, revealed a main effect of Target Category, $F(1, 32) = 368.05$, $p < .001$, $\eta_p^2 = 0.92$, with faster RTs for non-social than social trials (540 ms vs. 680 ms). The main effect of Congruency was not significant ($F < 1$), but there was a significant Target Category × Congruency interaction, $F(1, 32) = 23.16$, $p < .001$, $\eta_p^2 = 0.42$. Similarly to Experiment 1, responses to non-social trials were faster for congruent than incongruent trials (531 vs. 549 ms), $F(1, 32) = 13.88$, $p < .001$, $\eta_p^2 = 0.30$; whereas in social trials responses were faster for incongruent than congruent trials (668 ms vs. 693ms), $F(1, 32) = 8.40$, $p = .007$, $\eta_p^2 = 0.21$.

As for the effects of previous trials, we observed a significant main effect of Previous Target Category, $F(1, 32) = 36.98$, $p < .001$, $\eta_p^2 = 0.54$, with faster RTs for target category repetitions than alternations (602 vs. 619 ms). Importantly, the significant two-way Congruency × Previous Congruency interaction, $F(1, 32) = 64.67$, $p < .001$, $\eta_p^2 = 0.67$, reflected the expected pattern of CSE, which was modulated by Target Category, as reflected by the a significant three-way Target Category × Congruency × Previous Congruency interaction, $F(1, 32) = 4.58$, $p = .040$, $\eta_p^2 = 0.13$. Separate ANOVAs conducted for each target category reflected significant CSE for both non-social, $F(1, 32) = 41.53$, $p < .001$, $\eta_p^2 = 0.57$, and social trials, $F(1, 32) = 40.99$, $p < .001$, $\eta_p^2 = 0.56$, but with opposing patterns. Pair-wise comparisons showed that, non-social targets reflected positive congruency effects after congruent trials (39 ms, $p < .001$), that disappeared after incongruent trials (-3 ms, $p = .657$). In contrast, social targets reflected a significant advantage for responding to incongruent trials present after following incongruent trials (-57 ms, $p < .001$), which was absent after congruent trials (8 ms, $p = .469$).

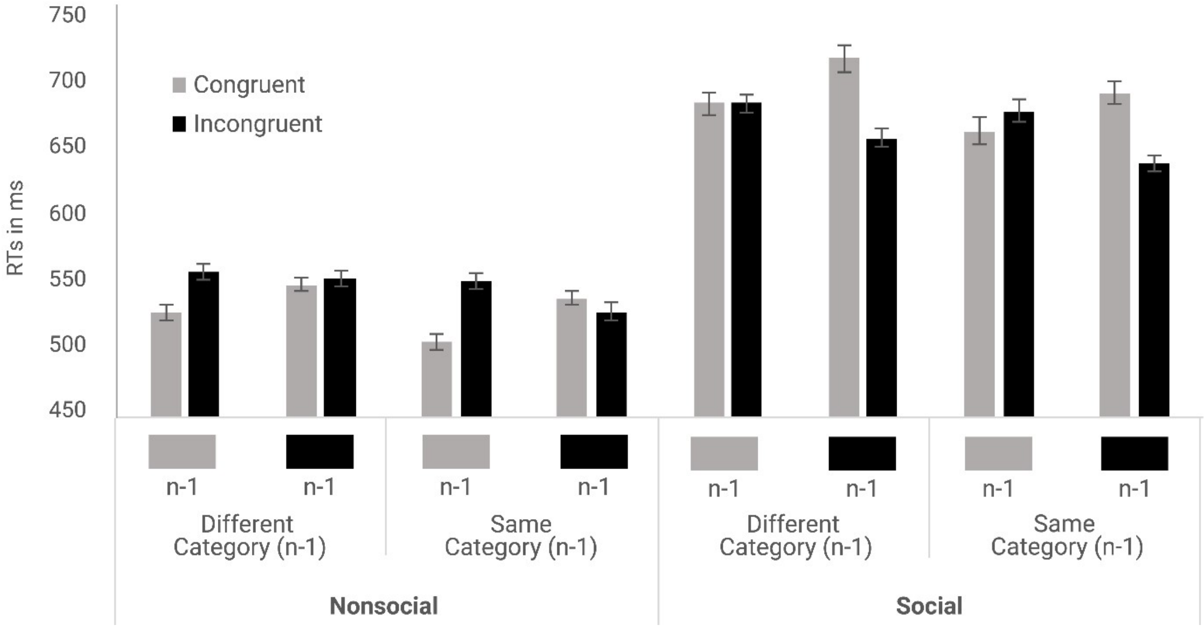
Contrary to Experiment 1, the modulation of CSE by Previous Target Category did not reach statistical significance in the overall analysis, $F(1, 32) = 2.62$, $p < .115$, $\eta_p^2 = 0.08$. However, separate ANOVAs focused on specific CSE patterns for target category repetitions (same previous target category) and alternations (different previous target category) between non-social and social targets in consecutive trials yielded a significant Congruency × Previous Congruency interaction, $F(1, 32) = 42.74$, $p < .001$, $\eta_p^2 = 0.57$, for sequences involving the *same previous target category*, which was not modulated by Target Category ($F < 1$). Thus, as hypothesized, the CSE was significant both for consecutive non-social trials (i.e., arrow-arrow), $F(1, 32) = 32.94$, $p < .001$, $\eta_p^2 = 0.51$, and for consecutive social trials (i.e., gaze-gaze), $F(1, 32) = 19.06$, $p < .001$, $\eta_p^2 = 0.37$. As shown in Figure 4, for non-social targets (arrows), larger differences in favor of congruent trials arose after congruent trials (47 ms, $p < .001$), whereas an opposite non-significant trend was observed after incongruent trials (-11 ms, $p = .204$). In contrast, for social trials (gaze), showing a negative congruency effect, the effect became more favorable to incongruent trials when they followed another incongruent trial (-53 ms, $p < .001$), which was not significantly reversed after congruent trials (16 ms, $p = .228$).

The ANOVA conducted for *different previous target category* revealed a significant Congruency × Previous Congruency interaction, $F(1, 32) = 28.01$, $p < .001$, $\eta_p^2 = 0.47$, as well as a three-way Target Category × Congruency × Previous Congruency interaction, $F(1, 32) = 4.55$, $p = .041$, $\eta_p^2 = 0.12$. Separate ANOVAs conducted for each target category showed a significant Congruency × Previous Congruency interaction for both social–non-social successions, $F(1, 32) = 8.78$, $p =$

.006, η_p^2 = 0.22) and non-social–social successions, $F(1, 32) = 20.76$, $p < .001$, η_p^2 = 0.39. As shown in Figure 4, this reflects the same pattern described for successions involving the same target category, with significant advantages for congruent non-social trials following congruent social trials (32 ms, $p < .001$), which were absent after incongruent social trials (5 ms, $p = .562$), and a significant advantage for incongruent social trials following incongruent non-social trials (-61 ms, $p < .001$), but not after a congruent non-social trial (-0.4 ms, $p = .974$).

Figure 4.

Average RTs for Experiment 2.



Note. Error bars represent the SEM adjusted with Cousineau's (2005) method to eliminate between-participants' variability.

Error Rates

The overall ANOVA on error rates, reflected a significant main effect of Target Category, $F(1, 32) = 39.35$, $p < .001$, η_p^2 = 0.55, showing lower error rates for non-social (.01) than for social trials (.08), in absence of other significant main effects. There was a significant Congruency × Previous Congruency interaction, $F(1, 32) = 30.17$, $p < .001$, $\eta_p^2 = 0.49$, as well as a three-way Target Category × Congruency × Previous Congruency interaction, $F(1, 32) = 7.77$, $p = .009$, $\eta_p^2 = 0.20$. Social trials produced a significant Congruency × Previous Congruency interaction, $F(1, 32) = 20.30$, $p < .001$, $\eta_p^2 = 0.39$, but no significant main effects of Congruency, nor of Previous Congruency ($F < 1$). In contrast, non-social trials produced a significant Congruency × Previous Congruency interaction, $F(1, 32) = 14.55$, $p = .001$, $\eta_p^2 = 0.31$, as well as significant main effects of Congruency, $F(1, 32) = 5.94$, $p = .021$, $\eta_p^2 = 0.16$, and Previous Congruency, $F(1, 32) = 6.37$, $p = .017$, $\eta_p^2 = 0.17$, reflecting greater accuracy for congruent than incongruent trials, and for trials immediately following incongruent trials.

Despite non-significant interactions involving Previous Target Category, we tested our prediction that the CSE pattern should be analogous, regardless of the succession type for each Target Category. The ANOVA for successions involving the *same previous target category* showed a significant Congruency × Previous Congruency interaction, $F(1, 32) = 29.08$, $p < .001$, $\eta_p^2 = 0.48$, modulated by Target Category, $F(1, 32) = 9.14$, $p = .005$, $\eta_p^2 = 0.22$. This latter interaction reflects a fully crossed pattern for social targets, compared to non-social targets, presumably because the latter trials were affected by floor effects. Importantly, the Congruency × Previous Congruency interaction was significant both for consecutive non-social trials, $F(1, 32) = 12.68$, $p = .001$, $\eta_p^2 = 0.28$, and for consecutive social trials, $F(1, 32) = 18.94$, $p < .001$, $\eta_p^2 = 0.37$, indicating an overall advantage for responding to congruent non-social trials after another congruent trial and a similar advantage for incongruent social trials after another incongruent trial.

Finally, the ANOVA conducted for ***different previous target category*** also showed the crucial Congruency × Previous Congruency interaction, $F(1, 32) = 11.31$, $p = .002$, $\eta_p^2 = 0.26$, which in this case was not significantly modulated by Target Category ($F < 1$). Separate analyses confirmed a significant Congruency × Previous Congruency interaction both for non-social trials preceded by social trials, $F(1, 32) = 7.28$, $p = .011$, $\eta_p^2 = 0.19$, and for social trials preceded by non-social trials, $F(1, 32) = 7.08$, $p = .012$, $\eta_p^2 = .18$.

Discussion of Experiment 2

The results of Experiment 2 replicated all the relevant findings of Experiment 1, reinforcing its provisional conclusions. The third conceptual scenario, presented as a framework to account for the results, and now proposed as a set of pre-registered hypotheses, was strongly supported by replicating the same pattern. Nonetheless, it was outstanding whether these stimulus-specific CSE patterns are linked to the particular stimuli used in both experiments, or whether they generalize across other types of social and non-social stimuli.

5.5 EXPERIMENT 3

Experiment 3 was conducted in order to not only further replicate the previous results shown in Experiments 1 and 2, but especially to determine whether the observed CSE effects are explained by particular characteristics of the stimuli (arrow and gaze) used in both experiments, or whether they generalize more broadly across other social and non-social stimuli. Therefore, in the current experiment, in addition to eyes and arrows, the targets would also include a full face containing a directional gaze or a directional written word. We hypothesize that when using other additional social and non-social stimuli, we would observe: (a) standard CSE for non-social stimuli regardless of them being preceded by the same stimulus category and stimulus type (e.g., arrow-arrow), same category but different type (e.g., arrow-word) or different category (e.g., arrow-face); (b) and reversed CSE for social stimuli regardless of the preceding stimulus category or type.

Method

Participants

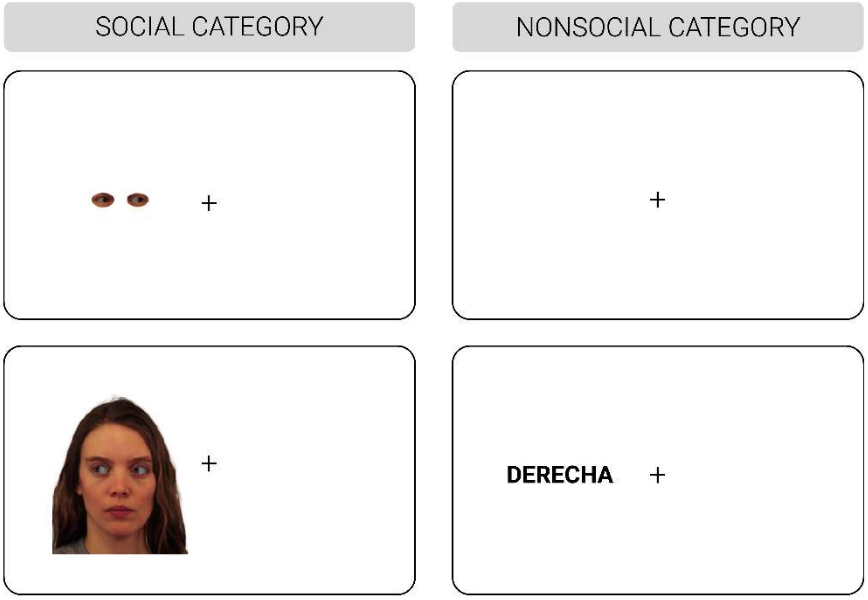
A new sample of 42 healthy volunteers (34 women, mean age = 21.21, *SD* = 2.48, range = 18-29 years) from the University of Granada participated voluntarily in the experiment in exchange for course credit (0.1 credit) or a monetary compensation (6€) for their time.

Material, apparatus, and stimuli

Apparatus and stimuli (arrows and gaze) were identical to those used in Experiment 2, except for the stimulus location, as they were aligned with the center of the Y-axis, leveled with the fixation point, as in Experiment 1. In addition, two new stimuli were added to each level of Target Category. For the social target category, it was a full face (50% female and 50% male) of an approximate size of 10.5 × 11 cm, portraying either left or right-looking eyes. For the non-social target category, it was a written uppercase word of an approximate size of 5-6 × 1 cm, indicating either left or right in Spanish (respectively "IZQUIERDA" or "DERECHA"). As in Experiment 1 and 2, the four stimuli were presented either on the left or right of the fixation point (see Figure 5). The distance from the fixation point to the center of the lateral stimulus was 10.5 cm. Full Face stimuli were obtained from the NimStim Set of Facial Expressions (https://danlab.psychology.columbia.edu/content/nimstim-set-facial-expressions), and edited in Adobe Photoshop 2021. Word stimuli were created in Power Point (Microsoft Office Professional Plus 2013), setting words at the same size as the arrows and gaze of previous stimuli.

Figure 5.

All four stimuli used for Experiment 3, divided by category.



Note. The upper row shows the same stimuli used for Experiment 2, and the lower row shows examples of the two additional stimulus types used for Experiment 3.

Procedure

The procedure and timing were identical to Experiment 2, except for the number of trials. In order to account for the two new stimuli, we doubled the number of trials obtaining a total of 512, divided across 4 blocks with a short break in between.

Design

The same design and analyses as in Experiment 1 and 2 were first performed for Experiment 3. As in Experiment 1 and 2, the experimental design was a two-factor repeated measures design (ANOVA) with Target Category (2, social and non-social), and Congruency (2, congruent and incongruent) as two within-participant factors, with 128 observations per experimental condition. Additionally, the variables pertaining to the previous trial were coded offline leading to the same two additional variables: Previous Congruency (2, congruent and incongruent) and Previous Target Category (2, same and different). Considering all four variables, there was an average of 31,75 observations per experimental condition, ranging from 18 to 48. As two new stimuli were added in this experiment, each level of Target Category (social and non-social) contained two types of stimuli (social: gaze and face and non-social: arrows and word). Due to this, an additional ANOVA was conducted, considering three levels in the Previous Target Category variable (Different Category, Same Category-Different Stimuli, Same Category-Same Stimuli).

Results

Data from 2 participants were excluded because no valid data were obtained during several blocks. For the remaining participants, we excluded the first trial of each block (0,78%), error trials (7.14%), trials following an error (7.10%), and trials with RTs above 1300 ms (1.14%) and below 200 ms (1.12%), following the same data filtering as Experiment 1 and 2. Mean RTs and error rates for each experimental condition are shown in Table 3.

Table 3.

Mean reaction times (RT) and error rates, and their corresponding standard deviations (SD) for sequential trials of Experiment 3.

				RT		Error rates	
TC	Pre -TC	Pre -CC	C	Mean	*SD*	Mean	*SD*
Non-social (Arrow or Word)	Different	C	C	610	*78*	0.016	*0.033*
			I	641	*75*	0.055	*0.071*
		I	C	634	*74*	0.031	*0.040*
			I	626	*76*	0.042	*0.053*
	Same	C	C	589	*70*	0.016	*0.039*
			I	636	*83*	0.078	*0.104*
		I	C	622	*77*	0.032	*0.050*
			I	616	*81*	0.054	*0.069*
Social (Gaze or Face)	Different	C	C	733	*90*	0.012	*0.037*
			I	715	*88*	0.063	*0.083*
		I	C	742	*92*	0.032	*0.054*
			I	704	*92*	0.012	*0.030*
	Same	C	C	708	*83*	0.070	*0.073*
			I	712	*93*	0.104	*0.112*
		I	C	729	*89*	0.094	*0.113*
			I	679	*82*	0.080	*0.092*

Note: TC (Target Category of current trial), Pre-TC (Previous Target Category, either same or different), Pre-C (Previous Congruency, either congruent (C) or incongruent (I)), C (congruency of the current trial).

Reaction Time

The overall ANOVA conducted on RTs with Target Category (non-social and social), Previous Target Category (same and different), Previous Congruency (congruent and incongruent) and Congruency (congruent and incongruent) as repeated measures revealed a main effect of Target Category, $F(1, 39) = 117.41$, $p < .001$, $\eta_p^2 = 0.75$, with faster RTs for non-social than social trials (622 ms vs. 715 ms). The main effect of Congruency was not significant, $F(1, 39) = 1.80$, $p = .187$, $\eta_p^2 = 0.04$, however, and more importantly, there was a significant Target Category × Congruency interaction, $F(1, 39) = 68.07$, $p < .001$, $\eta_p^2 = 0.64$. Similarly to Experiments 1 and 2, planned comparisons showed that with non-social stimuli, RTs were significantly slower for incongruent (630 ms) than for congruent trials (614 ms), $F(1,39) = 18.84$, $p < .001$, $\eta_p^2 = 0.33$. In contrast, for social stimuli, RTs were significantly faster for incongruent (702 ms) than for congruent trials (728 ms), $F(1,39) = 26.55$, $p < .001$, $\eta_p^2 = 0.41$.

In relation to the effect of the preceding trial, the ANOVA revealed a main effect of Previous Target Category, $F(1, 39) = 30.91$, $p < .001$, $\eta_p^2 = 0.44$, with faster RTs for repetitions of the same previous target category, than alternations of a different previous target category (661 vs. 676 ms). The interaction between Congruency and Previous Congruency was significant, $F(1, 39) = 61.74$, $p < 001$, $\eta_p^2 = 0.61$, reflecting the expected patterns of CSE which, furthermore, were modulated by Previous Target Category, $F(1, 39) = 7.13$, $p = .011$, $\eta_p^2 = 0.16$.

To explore the type of CSE that arose in each condition, we conducted two separate ANOVAs, one for each succession type (same or different previous target category). The ANOVA conducted for the *same previous target category* showed a significant interaction between Congruency and Previous Congruency, $F(1, 39) =$

50.38, p < 001, η_p^2 = 0.56, that was not modulated by Target Category (F < 1). Thus, as in Experiment 1 and 2, the CSE was significant both for consecutive non-social trials, F(1, 39) = 32.23, p < .001, η_p^2 = 0.45, and for consecutive social trials, F(1, 39) = 19.28, p < .001, η_p^2 = 0.33. For non-social trials, larger differences in favor of congruent trials arose after congruent trials (47 ms, p < .001), which disappeared after incongruent trials (-6 ms, p = .320). In contrast, for social trials —showing a negative congruency effect— the effect became more favorable to consecutive incongruent trials (-50 ms, p < .001), but disappeared after congruent trials (4 ms, p = .693).

The ANOVA conducted for *different previous target category* revealed a significant Congruency x Previous Congruency interaction, F(1, 39) = 23.37, p < .001, η_p^2 = 0.38, again not modulated by Target Category, F(1,39) = 1.38, p = .247, η_p^2 = 0.03. Specific analyses conducted on CSE in each transition type showed an interaction for both social–non-social successions, F(1, 39) = 17.35, p < .001, η_p^2 = 0.31, and non-social–social successions, F(1, 39) = 3.45, p = .071, η_p^2 = 0.08, although it did not reached statistical significance for the latter. For non-social trials, larger differences in favor of consecutive congruent (31 ms, p < .001) were observed, which were non-significantly reversed after incongruent trials (-8 ms, p = .260). In contrast, for social trials —showing a negative congruency effect— the effect became more favorable for consecutive incongruent trials (-38 ms, p < .001), which became smaller, although still significant, after congruent trials (-18 ms, p = .016).

Contrary to Experiment 2, the modulation of CSE by Target Category did not reach statistical significance in the overall analysis (F < 1).

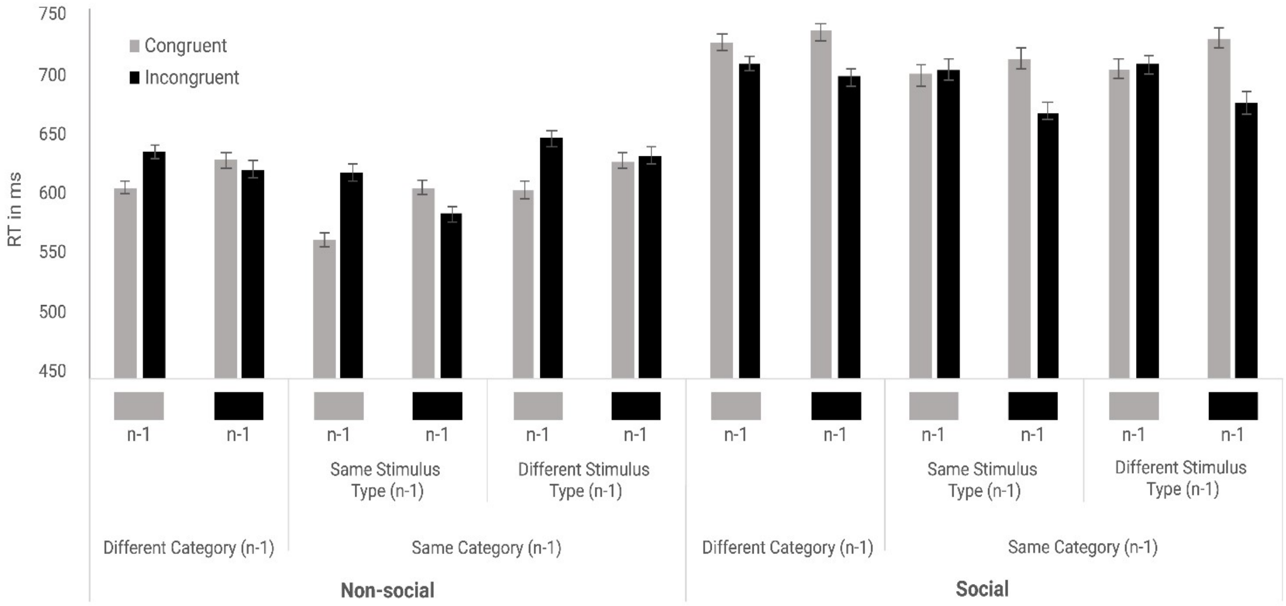
In Experiment 3, we specifically wanted to investigate whether CSE can occur not only between two different stimuli belonging to a different category or between the same stimuli, but also between two different stimuli that belong to the same category. For this purpose, we performed two separate ANOVAs considering three levels in the Previous Target Category variable (Different Category, Same Category-Different Stimuli, and Same Category-Same Stimuli), to aim to explore the type of CSE that arose in each condition, one for each Target Category (non-social and social) of the current trial (see Figure 6).

The ANOVA conducted for the *non-social target category* revealed a significant Congruency × Previous Congruency interaction, $F(1, 39) = 53.48$, $p < .001$, $\eta_p^2 = 0.58$, modulated by Previous Target Category, $F(2, 78) = 3.92$, $p = .024$, $\eta_p^2 = 0.09$. For non-social trials with a *different previous target category*, the Congruency × Previous Congruency interaction was significant, $F(1, 39) = 17.35$, $p < .001$, $\eta_p^2 = 0.31$. Specific analyses conducted on CSE showed significant differences after congruent trials, in favor of congruent trials (31 ms, $p < .001$), and no significant differences after incongruent trial (-8 ms, $p = .260$). For non-social trials with the *same previous target category-different stimuli*, the Congruency × Previous Congruency interaction was significant, $F(1, 39) = 9.60$, $p = .004$, $\eta_p^2 = 0.20$. Specific analyses conducted on CSE showed significant differences after congruent trials, in favor of congruent trials (44 ms, $p < .001$), and non-significant differences after incongruent trials (-4 ms, $p = .582$). For non-social trials with the *same previous target category-same stimuli*, the Congruency × Previous Congruency interaction was significant, $F(1, 39) = 43.67$, $p < .001$, $\eta_p^2 = 0.53$). Specific analyses conducted on CSE showed significant differences after congruent trials, in favor of congruent trials (55 ms, $p < .001$), and significant differences after incongruent trial, in favor of incongruent trials (-21 ms, $p = .025$).

The ANOVA conducted for *social target category* revealed a significant Congruency × Previous Congruency interaction, $F(1, 39) = 21.95$, $p < .001$, $\eta_p^2 = 0.36$, not modulated by Previous Target Category, $F(2, 78) = 2.31$, $p = .106$, $\eta_p^2 = 0.06$. For social trials with a *different previous target category*, the Congruency × Previous Congruency interaction did not reach statistical significance, $F(1, 39) = 3.45$, $p = .071$, $\eta_p^2 = 0.08$. Specific analyses conducted on CSE showed large significant differences, in favor of incongruent trials, after incongruent trials (-38 ms, $p < .001$), which were largely reduced, although still significant, after congruent trials (-18 ms, $p = .016$). For social trials with the *same previous target category-different stimuli*, the Congruency × Previous Congruency interaction was significant, $F(1, 39) = 13.07$, $p < .001$, $\eta_p^2 = 0.25$. Specific analyses conducted on CSE showed large significant differences, in favor of incongruent trials, after incongruent trials (-54 ms, $p < .001$), but no significant differences after congruent trials (4 ms, $p = .757$). For social trials with the *same previous target category-same stimuli*, the Congruency × Previous Congruency interaction was significant, $F(1, 39) = 11.80$, $p = .001$, $\eta_p^2 = 0.23$. Specific analyses conducted on CSE again showed large significant differences, in favor of incongruent trials, after incongruent trials (-45 ms, $p < .001$), and no significant differences after congruent trials (5 ms, $p = .703$).

Figure 6.

Average RTs for Experiment 3.



Note. Error bars represent the SEM adjusted with Cousineau's method (2005) to eliminate between-participants' variability. Note that the results from the Different Category and Same Category-Same Stimulus Type replicates the findings from Experiments 1 and 2, whereas results from the Same Category (Same vs. Different Stimulus Type) show that CSE also transfer between different stimulus type within the same category.

Error Rates

The overall ANOVA on error rates, reflected a significant main effect of Target Category, $F(1, 39) = 23.32$, $p < .001$, $\eta_p^2 = 0.37$, showing lower error rates for non-social (.04) than for social trials (.09). The main effect of Congruency was also significant, $F(1, 39) = 6.68$, $p = .014$, $\eta_p^2 = 0.15$, showing lower error rates for congruent (.05) than for incongruent trials (.07), in absence of other significant main effects. There was a significant Congruency × Previous Congruency interaction, $F(1, 39) = 46.11$, $p < .001$, $\eta_p^2 = 0.54$, reflecting the expected pattern of CSE, as well as a three-way Target Category × Congruency × Previous Congruency interaction, $F(1, 39) = 5.17$, $p =.029$, $\eta_p^2 = 0.12$. Non-social trials produced a significant Congruency ×

Previous Congruency interaction, $F(1, 39) = 26.52$, $p < .001$, $\eta_p^2 = 0.41$. Social trials also produced a significant Congruency × Previous Congruency interaction, $F(1, 39) = 29.62$, $p < .001$, $\eta_p^2 = 0.43$.

The three-way Previous Target Category × Congruency × Previous Congruency interaction was significant, $F(1, 39) = 7.89$, $p = .008$, $\eta_p^2 = 0.17$. The ANOVA for successions involving the *same previous target category* showed a significant Congruency × Previous Congruency interaction, $F(1, 39) = 40.67$, $p < .001$, $\eta_p^2 = 0.51$, modulated by Target Type, $F(1, 39) = 4.54$, $p = .039$, $\eta_p^2 = 0.10$. As in Experiment 2, this latter interaction reflects a fully crossed pattern for social targets, compared to non-social targets, presumably because the latter trials were affected by floor effects. Importantly, the Congruency × Previous Congruency interaction was significant both for non-social–social trials, $F(1, 39) = 22.80$, $p < .001$, $\eta_p^2 = 0.37$, and for social–social trials, $F(1, 39) = 25.58$, $p < .001$, $\eta_p^2 = .40$, indicating an overall advantage for responding to consecutive congruent non-social trials and a similar advantage for consecutive incongruent social trials.

The ANOVA conducted for *different previous target category* also showed the crucial Congruency × Previous Congruency interaction, $F(1, 39) = 13.77$, $p < .001$, $\eta_p^2 = 0.26$, but in this case not significantly modulated by Target Category, $F(1, 39) = 1.28$, $p = .265$, $\eta_p^2 = 0.03$. Separate analyses confirmed a significant Congruency × Previous Congruency interaction both for non-social trials preceded by social trials, $F(1, 39) = 6.32$, $p = .016$, $\eta_p^2 = 0.14$, and for social trials preceded by non-social trials, $F(1, 39) = 9.27$, $p = .004$, $\eta_p^2 = 0.19$.

Discussion of Experiment 3

The results of Experiment 3 replicated all the relevant findings of Experiment 1 and 2, observing the dissociation of the congruency effect previously obtained for gaze and arrows with other stimuli, such as a full face and a word, in a within-block design. A standard congruency effect was found with non-social targets (arrow and word), with faster RTs for congruent than incongruent trials. In contrast, a reversed congruency effect was found for the social target (cropped eyes and full face), with faster RTs for incongruent than congruent trials.

Regarding CSE, standard CSE are observed for consecutive non-social trials, with increased congruency effects after congruent trials; and this is independent of the type of non-social stimuli used since it was found with arrow trials and word trials. On the contrary, reversed CSE are observed for consecutive social trials, facilitating responses to consecutive incongruent social trials, with the two social stimuli (full face and cropped eyes). Importantly, the same pattern of CSE was obtained regardless of the target category (same or different) presented on preceding trials, reflecting the same pattern of cross-conflict sequential effects trials but in opposite directions. These findings indicate that CSEs are driven by sharing the same type of spatial congruency. We explored what occurs with consecutive trials within the same category when the stimuli are different. For non-social stimuli, we observed standard CSE for arrow trials following word trials (or vice versa), with increased congruency effects after congruent trials. For social stimuli, we observed reversed CSE for gaze trials following face trials (or vice versa), with increased congruency effects after incongruent trials.

These findings rule out that the observed CSEs are due to particular features of the arrow and gaze stimuli, supporting the idea that different stimuli belonging to the same-stimulus-category have the same processing mechanism, which seems to be particular for social and non-social stimuli. These data indicate that standard CSE are observed between different stimuli with the same spatial congruency properties, although they seem not to transfer between different response modalities (Janczyk & Leuthold, 2018).

5.6 General discussion

In the present experiments, a spatial interference task was used to investigate whether attentional mechanisms elicited by gaze stimuli differed from those elicited by non-social pointers such as arrows. Previous results by Cañadas & Lupiáñez (2012) and Marotta et al. (2018) found opposite interference effects prompted by social and non-social stimuli in separate experiments and counterbalanced blocks. Here, we conducted three consecutive experiments where both types of stimuli were randomly interspersed to assess whether the reversed congruency effect observed on social targets (full-face or cropped eyes) would also arise on a trial-by-trial basis, and to explore possible carry-over effects between successive trials featuring different types of targets.

The results of these experiments, on the one hand, fit nicely with the results described in the existing literature, showing that: (a) responses to non-social stimuli (i.e., arrows and words) are more efficient when the stimulus' direction and its location are coherent with each other (congruent), whereas (b) responses to social stimuli (i.e., gaze and faces) are faster and more accurate when they "look" opposite to their actual location (incongruent). On the other hand, the results also revealed the following theoretically relevant findings: (a) the reversed congruency effect observed with social stimuli (i.e., gaze or faces) arises on a trial-by-trial basis, and thus cannot be explained by the adoption of a global "social" strategy. This possibility could not be ruled out by the results obtained in previous studies that presented the stimuli in separate blocks (Marotta et al., 2018b). However, replicating the effect in this study (Experiments 1 and 2) that interspersed gaze and arrows randomly within blocks clearly showed that the observed dissociation between social and non-social pointers must be due to actual differences in the conflict elicited by each specific type of trial. Moreover, regarding the sequential effects, (b) a specific pattern of CSE arose for non-social and social trials, strengthening the effect produced by each type of trial when the preceding trial belonged to the same congruency type. Thus, for arrow trials, the congruency effect is stronger after another congruent arrow trial, and for gaze trials, there is a stronger advantage for responding to an incongruent trial after another incongruent gaze trial. Importantly, as shown through Experiment 3, these stimulus-category-specific patterns replicate across other types of social and non-social stimuli (such as words or full faces): standard CSE emerged between different non-social stimuli within the same category, and reversed CSE emerged between different consecutive social stimuli.

Finally, and perhaps most importantly, the results from each of the three experiments also show that (c) both types of CSEs arise even in cross-conflict successions, regardless of whether the preceding type of target was of the same or the opposite type (e.g., gaze-gaze or arrows-gaze). Thus, the obtained pattern of CSE depends critically on whether the two successive trials belong to the same class of spatial congruency, but not on whether they belong to the same type of target, nor on the relative efficiency of the preceding outcome (i.e., whether the congruency of the preceding trial led to faster or slower responses).

Having ruled out an explanation of the reversed congruency effect for social stimuli based on adopting a global strategy for social stimuli, we may center on our main aim of elucidating the mechanisms behind conflict processing of social and non-social stimuli. The patterns of CSE observed in the present experiments in successions of the same type of stimulus, are consistent with previous studies (Funes et al., 2010; Torres-Quesada et al., 2014), as responses to arrow trials were more efficient for congruent than incongruent trials, and the effect was enhanced after another congruent arrow trial, reflecting standard CSE, and responses to gaze trials were more efficient for incongruent trials, and this effect was also increased after another incongruent gaze trial, reflecting a reversed CSE. Most notably, however, both types of CSE were observed regardless of whether the preceding target was of the same stimulus type (i.e., in arrow-arrow and gaze-gaze successions) or a different one (i.e., gaze-arrow or arrow-gaze). Therefore, despite previous evidence on the specificity of CSE (Egner, 2008; Egner et al., 2007; Funes et al., 2010), the present results show a certain generalization across stimuli. Moreover, even though the pattern of congruency effects and CSE depended on the type of target, the nature of the preceding target did modulate sequential effects only quantitatively, but not qualitatively. The slightly larger CSE for successions of the same target type is consistent with the idea that the effect is mediated by episodic representations (Dignath et al., 2019), as repetitions of the same stimulus could help retrieve processes responsible for CSE. However, the most important finding was the robust and qualitatively similar CSE patterns observed for each stimulus type, both for target type repetitions and alternations.

Regarding the pattern of sequential effects observed in cross-conflict trials, we had proposed two a priori scenarios assuming that CSE should either not be observed —considering that congruency effects for each stimulus are conflict-specific (Egner, 2008; Egner et al., 2007; Funes et al., 2010)—, or that they would reflect a general update of the amount of control required on each trial, based on the amount of conflict encountered on the previous trial (as inferred by the efficiency of responding, see Botvinick, 2007). In this latter scenario, efficient responses to incongruent gaze trials should provoke a decrease of control for the following trials, which in turn could increase the influence of irrelevant features, and therefore, the congruency effect observed in an upcoming arrow trial. Analogously, after responding efficiently to congruent arrow trials, a decrease in control should lead to a corresponding increase in the (reversed) congruency effect usually found in response to gaze trials. However, these two scenarios were disconfirmed by the results of Experiment 1, which pointed towards a third scenario that was tested through Experiments 2 and 3. This third scenario was built on the ideas that (a) sequential effects are factor-specific, (b) arrow and gaze trials share a non-social spatial interference factor, but (c) they differ in an additional social factor that is exclusive to gaze stimuli. Thus, the common spatial factor would be responsible for the sequential modulation of congruency observed between types of trials, whereas the specific social factor that is present in gaze trials could be responsible for the net effect obtained with these social stimuli.

Thus, for gaze-arrows successions, the spatial congruency between the location of a preceding gaze trial and its required response would have standard effects on responding to a successive arrow trial, increasing the congruency effect, even if the response to the previous gaze trial was rather inefficient, because of the superimposed social factor. Moreover, for gaze trials, the impact of the opposite looking factor would be ultimately responsible for the observed reversed congruency effect, but the spatial incongruence that would also be present on these trials would tend to decrease the strength of the social effect, and it would do so especially if the preceding trial was spatially congruent, regardless of whether it was an arrow trial or another gaze trial. According to this view and in resonance with our results, by assuming that every conflict source is controlled specifically based on its occurrence on the past trial, and that gaze and arrow trials share one common source of conflict, it is possible to explain how the same pattern of CSE arises with repeated and switched types of trials, even though the two stimuli ultimately produce opposite patterns of congruency effects.

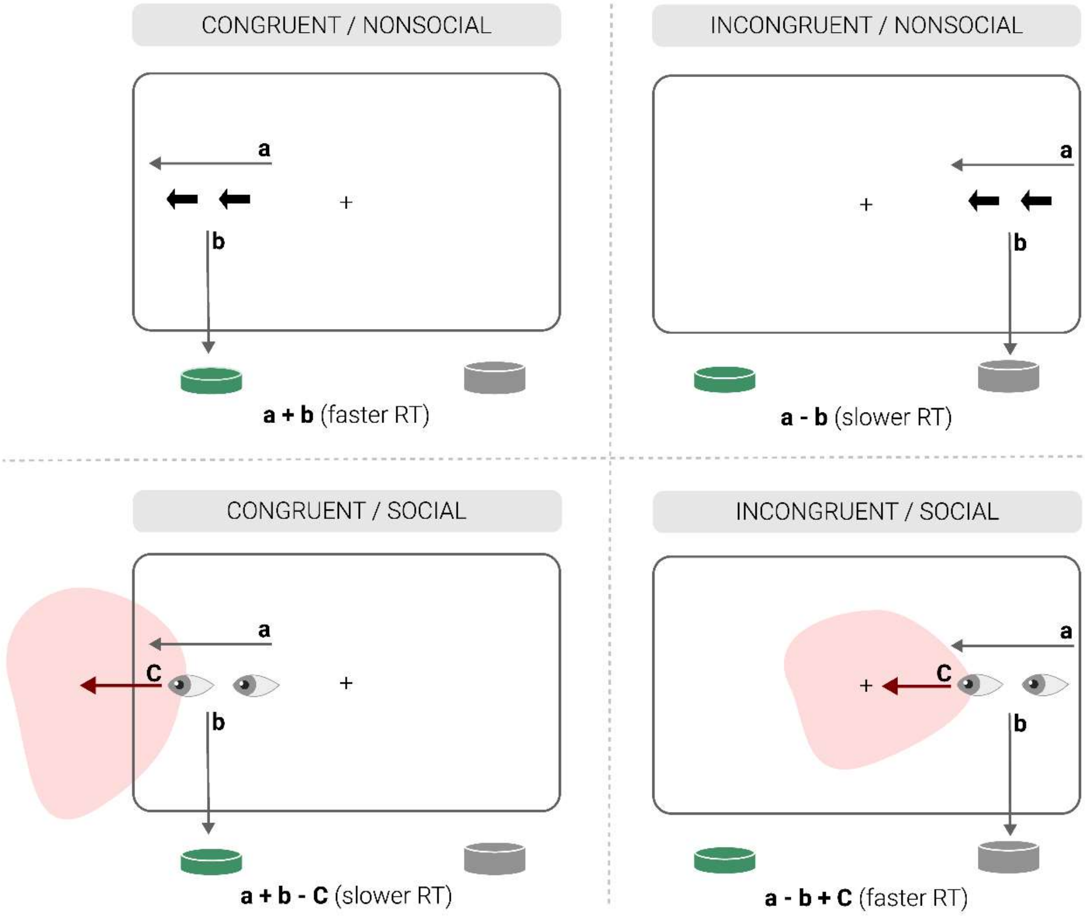
Indeed, this two-factor (spatial vs. social) account of gaze vs. arrows congruency effect is supported by a recent EEG study where similar congruency effects were observed for arrow and gaze trials on the early ERP components (P1, N1, and N170), while opposite congruency effects arose on their later components (N2 and P3). This suggests that, initially, the directional information of both arrows and gaze is processed relatively similarly, leading to similar spatial conflict. However, at later stages of processing, the social nature of gaze may invert the initial conflict, leading to the reversed congruency effect observed in the final responses due to further processing, arguably involving social cognition mechanisms (Marotta et al., 2019a).

The "Looking Vector": A Proposed Framework

Regarding the further and specific processing of gaze trials, it must be noted that, in contrast to arrow stimuli, eyes do not merely point towards a certain location, but actually look at it (Gamer & Hecht, 2007; Risko et al., 2016), making this location more salient, important, or otherwise active in that context. Thus, we surmise that the experience of these two types of target categories in the context of a spatial interference task may be coded as resulting from the action of three vectors represented in Figure 7: two of them would be common to social (i.e., face and gaze) trials and non-social (i.e., arrow and word) trials, and represent the forces of the stimulus' pointing direction (a) and its spatial location (b), that would lead to the spatial congruency effect. The third vector, however, would be specific to social stimuli, representing a “looking” vector (C) which, rather than merely coding gaze direction, could interact with other more complex social information, resulting in privileged access, attentional selection, and/or faster reaction to those contents associated with the location that the stimulus “looks” at. In this framework, incongruent non-social trials lead to slower RTs than congruent trials, due to the mismatch between the (relevant) direction of the non-social pointer (a), and its (irrelevant) location (b). However, even though in social trials the above-mentioned forces are also at play, the strength of the third "looking" vector (C) would counteract those forces. The strength of vector C is supported by the fundamental role played by gaze in communicative behavior (J. K. Hietanen, 2018), gaze following (Emery, 2000), joint attention (Emery, 2000; Mundy, 2018), or theory of mind (Simon Baron-Cohen, 1994; Emery, 2000).

Figure 7.

Visual representation of the different possible forces affecting responses (pressing the green button) for non-social and social trials.



Note. Two vectors are activated for both arrows and gaze: the directional vector (*a*) and the stimulus-response spatial vector (*b*). In gaze trials, a third force is present: the looking vector (*C*), which likely overpowers *b*. The looking vector on the bottom left panel illustrates the joint distraction explanation (attention is lead towards the pink field outside the task's context), whereas that on the bottom right panel illustrates the joint attention explanation (attention is lead to the pink field in the center of the task's context) for the reversed congruency effect observed for those targets.

In this sense, the hypothetical explanation inspired by our results could be easily linked to specific phenomena of social cognition, such as joint attention, where the gazes of two observers "meet" on an object. On incongruent social trials (e.g., when a gaze appears on the right, pointing toward the left), the eyes not only look towards the imperative response but also towards the central fixation point on the screen, where participants' gaze is fixed (pink area in the bottom right panel of Figure 7). Therefore, an effect of joint attention might further facilitate responding (Edwards et al., 2020), leading to the reversed congruency effects observed in these trials. However, it has been recently shown that, although joint attention is fully developed at age 4 (Mundy et al., 2007), the reversed congruency effect observed with gaze does not appear until early adolescence, and 4-year-old children show the same standard congruency effect for both arrows and gaze (Aranda-Martín et al., 2022).

On the other hand, on congruent social trials (e.g., when a gaze is located on the left and it is looking further to the left), the eyes are directed away from where the participants are looking towards (pink area in the bottom left panel of Figure 7). Here, a phenomenon that we could call *joint distraction*, may be at play, withdrawing attention from the relevant task area, consequently leading to the observed increase in RT in this situation. Although the results by Aranda-Martín et al. (2022) would discourage the joint attention explanation, distinguishing whether reversed congruency effects obtained with gaze trials are explained by a mechanism of joint attention, joint distraction, or a blend of both, should be the focus of future research. Importantly, these mechanisms could also explain the inwards bias observed in the perception of photographs and paintings: people prefer compositions in which faces looks inwards rather than outwards (Chen et al., 2018; Chen & Scholl, 2014). The outward gaze of the faces in the scene would draw the observer away from it, thus producing the effect of reversed congruency in our experimental procedure and non-preferred judgment on aesthetic preferences.

Beyond the discussed implications of these results regarding the impact of social factors on attentional control, they also have important consequences concerning the nature of CSE and its alternative interpretations, either as conflict-adaption effects (e.g., Botvinick, 2007) or as the result of general priming or priming of control (Egner, 2014; King et al., 2012). To our knowledge, these results represent the first case in the literature of cognitive control showing a significant increase in congruency effects occurring systematically after low-efficiency outcomes. This pattern is obtained, for instance, for social trials preceding non-social ones, where a slow response to a congruent gaze target is followed by an increase in the congruency effect observed in response to an upcoming arrow trial. This effect is deeply inconsistent with the idea that cognitive control must be upgraded after negative outcomes, and therefore that congruency effects should decrease precisely after such trials. Our results are far more consistent with a priming account of these dynamics, attributing the changes in performance between successive trials to the immediate repetition of certain processing components, in this case, the spatial congruency, that would be present in both social and non-social trials.

It is worth noting that it is not tenable to regard the observed CSE exclusively in terms of feature repetition priming (cf., Mayr et al., 2003), as sequences of trials including identical stimulus repetitions, different stimuli from the same category, as well as different stimuli from different categories yielded similar results. Indeed, cross-conflict sequences of trials could not possibly include an exact repetition across consecutive trials, but still, produced the same qualitative CSE produced by successions involving the same type of trials. Because the present paradigm is intrinsically built up in terms of two-choice tasks, it is not suitable to analyze the data after removing both whole and partial feature repetitions. Nonetheless, we surmise that the observed pattern, especially in switching target type successions, is more consistent with the idea of priming of control (Egner, 2014; King et al., 2012), according to which, having exerted a certain form of control in a given episode or context primes the same process to be exerted in future encounters with these conditions. Thus, regardless of the efficiency of the overall response or the amount of experienced conflict (Burle et al., 2005), which might be affected by specific components of the trial, having resolved a spatial conflict in one trial would improve the efficiency with which it would be solved on the next trial, diminishing the effect of that conflict, ultimately: (a) decreasing standard congruency effects on the next non-social trial, and (b) increasing reversed congruency effects on the next social trial.

Although the proposed framework coherently explains the observed data, more direct and empirical approaches supporting it are needed. For example, variables known to reduce spatial congruency effects with arrows could be manipulated to investigate whether they simultaneously increase reversed congruency effects for gaze trials. In this regard, presenting directional targets surrounded by irrelevant context has been found to reduce the spatial congruency effect produced by arrows trials, while leading to a corresponding increase in the reversed congruency effect observed in gaze trials (Román-Caballero et al., 2021a, 2021b).

Lastly, we must also consider that the consistently slower and less accurate responses produced by gaze trials could be partially accounted for by their relative difficulty or complexity compared to arrow trials. Future experiments should address this specifically by, for example, adding complexity to the non-social stimuli and/or simplifying the social stimuli (e.g., augmented size of eyes). Moreover, response speed can also be manipulated by other factors, such as the stimulus onset asynchrony (SOA). As a case in point, Cañadas and Lupiáñez (2012) found faster responses to gaze stimuli with increased SOAs, but yet no modulation of the pattern of congruency effects by this faster performance. While we cannot make evidence-based predictions on the above-explained modifications, it appears that the complexity of the gaze stimuli would not fully explain the pattern found in the present study, which would be observed regardless of the speed of responding.

5.7 Conclusion

The present study explores differences in congruency effects and CSE elicited by social vs. non-social stimuli in the context of a spatial interference task. The collected data reflect co-existing and shared attentional mechanisms producing congruency effects elicited by social and nonsocial stimuli that generalize from one type of stimulus to another. However, for social stimuli containing a gaze, we hypothesize an added dimension that could lead to a specific and reversed pattern of congruency effects and CSE. This latter characteristic seems to be unique to social stimuli, and thus, non-transferrable to nonsocial stimuli. In this context, it may be critical to understand why these differences between social and nonsocial attentional cues do not arise in standard gaze cueing paradigms (Brignani et al., 2009; Santiesteban et al., 2014; Stevens et al., 2008; Jason Tipples, 2008), whereas they are systematically observed in other paradigms that look for more qualitative differences between these two types of attentional orienting cues (Gregory & Jackson, 2017; Marotta et al., 2012).

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Pre-registration and data availability statement:

This study's design and hypotheses were preregistered; see https://osf.io/fw8dn and https://osf.io/r975q. The data of all three experiments of this study are openly available in an OSF (Open Science Framework) repository at https://osf.io/rfawj/ [doi: 10.17605/OSF.IO/RFAWJ].

Chapter 6

Second Study

Explicit vs. Implicit spatial processing in arrow vs. eye-gaze spatial congruency effects

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6.1 Abstract

Arrows and gaze stimuli lead to opposite spatial congruency effects. While standard congruency effects are observed for arrows (faster responses for congruent conditions), responses are faster when eye-gaze stimuli are presented on the opposite side of the gazed-at location (incongruent trials), leading to a reversed congruency effect (RCE). Here, we explored the effects of implicit vs. explicit processing of arrows and eye-gaze direction. Participants were required to identify the direction (explicit task) or the colour (implicit task) of left or right looking/pointing gaze or arrows, presented to either the left or right of the fixation point. When participants responded to the direction of stimuli, standard congruency effects for arrows and RCE for eye-gaze stimuli were observed. However, when participants responded to the colour of stimuli, no congruency effects were observed. These results suggest that it is necessary to explicitly pay attention to the direction of eye-gaze and arrows for the congruency effect to occur. The same pattern of data was observed when participants responded either manually or verbally, demonstrating that manual motor components are not responsible for the results observed. These findings are not consistent with some hypotheses previously proposed to explain the RCE observed with eye-gaze stimuli and, therefore, call for an alternative plausible hypothesis.

Keywords: arrows, gaze, implicit processing, attentional orienting, social attention, reversed congruency effect, spatial interference task.

6.2 Introduction

The ability of human beings to perceive, attend, and adequately respond to other people's gaze direction has been crucial to their survival. This ability provides a valuable source of information about what others are attending to and may have evolved from the need to detect food, predators, and other sources of threat (Emery, 2000).

Thus, gaze does not only allows us to explore our environment and extract relevant information, but has also a critical non-verbal communicative function (Itier & Batty, 2009). Through gaze, we can communicate socially relevant information, such as our focus of interest, private thoughts, emotions, and intentions (e. g., Baron-Cohen et al., 1997). According to Baron-Cohen's account for social cognition (1995), the human brain has developed a specialized module called "eye-direction detection", which serves to identify the presence and direction of gaze, as well as eye-contact (Macrae et al., 2002).

During visual search tasks, direct gaze (which refers to situations in which the eye-gaze stimuli and the participant's gaze make visual contact) is detected faster than averted gaze. Direct gaze or eye-contact facilitates judgments regarding different aspects of the eyes or faces. According to the literature, direct gaze (as compared to averted gaze) improves attentional orienting towards the faces (Mares et al., 2016), and improves the discrimination of emotions (Hamilton, 2016; J. K. Hietanen et al., 2008; McCrackin & Itier, 2019); in particular, angry and happy faces are better detected under conditions of direct gaze as compared to averted gaze, while fearful faces are detected more frequently under conditions of averted gaze as compared to direct gaze in an attentional blink task (Adams & Kleck, 2005; Milders et al., 2011).

Similarly, gender categorization of human faces is facilitated when gaze is directed toward the observer (i.e., a direct gaze), compared with situations where gaze is averted or the eyes are closed (Burra et al., 2018; Macrae et al., 2002). Furthermore, direct gaze facilitates social categorization of faces, according to either race or identity (Kloth et al., 2015; Macrae et al., 2002; Richeson et al., 2008). Direct gaze is also processed faster than averted gaze during unconscious processing (Chen & Yeh, 2012). All these observations suggest that the perception of direct eye-gaze triggers processes of preferential detection and a better allocation of attentional resources, which modulate cognitive processing and behavioural responses (which is known as the eye-contact effect, Conty et al., 2007; Senju & Johnson, 2009). Contrary, averted gaze causes an automatic shift of attention towards the observed direction. This ability to attend to the same object or place where another person is looking at is called “joint attention”, a crucial process for the typical development of many social skills such as language and the theory of mind (Conty et al., 2007; J. K. Hietanen et al., 2008).

In the last years, researchers have tried to evaluate the uniqueness of attentional mechanisms triggered by gaze cues, trying to dissociate attentional mechanisms triggered by gaze from those engaged by symbolic nonsocial directional stimuli such as arrows. It is important to note that arrow cues have a directional property, just like gaze, but no biological or social significance (Birmingham & Kingstone, 2009; Capozzi & Ristic, 2018). Most studies have used variants of the traditional spatial cueing paradigm (Chica et al., 2014; Posner, 1980) to compare attentional engagement produced by eye-gaze and arrows. In the spatial cueing paradigm, either eyes or arrows are used as attentional cues, presented at fixation, followed by targets presented at either the left or right location. Both gaze and arrow cues result in faster reaction times (RT) to targets appearing at the cued location compared to other locations (the so-called gaze/arrow cueing effect), even when eyes or arrows are not predictive of the subsequent target location, and even when the time interval between the presentation of the cue and the target is very short (for reviews see Birmingham & Kingstone, 2009; Capozzi & Ristic, 2018). This suggests the relatively reflexive nature of this effect. However, using the spatial cueing paradigm, subtle or no behavioural differences have been generally observed between eye-gaze and arrow cues, leading some authors (Heyes, 2014; Santiesteban et al., 2014) to propose that gaze attentional effects are at least partially driven by a domain-general attentional process.

However, a different pattern of results emerges in paradigms aiming at investigating qualitative differences between gaze and arrows. For example, whereas gaze direction orients attention to the specific spatial location or part of the object looked at, arrows spread attention through the whole cued object (Chacón-Candia et al., 2020; Marotta et al., 2012). Gaze seems to selectively focus attention on and automatically select the specific location/part of the object looked at, rather than simply initiating the orienting of attention, as arrows do (Marotta, Casagrande, et al., 2013). Moreover, combining a traditional gaze cueing paradigm with a visual working memory task, eye-gaze but not arrow cues enhanced visual working memory accuracy for cued information (Dodd et al., 2012; Gregory & Jackson, 2017). Thus, arrows and gaze seem to orient attention similarly towards the indicated/looked at direction. However, gaze seems to go beyond attentional orienting and further trigger location/object selection and its transfer into working memory.

Another paradigm has recently been used to more clearly dissociate the attentional effects of arrows and eye-gaze. Using a variant of the spatial Stroop task, in which eye-gaze or arrows were used as target stimuli, Marotta et al. (2018) observed that arrow and eye-gaze stimuli led to opposite spatial interference effects. In this paradigm, participants had to discriminate the direction of the targets (arrows or eye-gaze) unpredictably appearing to the left or right of the fixation point. Consistent with a Spatial Stroop effect (Lupiáñez & Funes, 2005), arrows elicited faster responses when their direction was congruent with their position (e.g., a left-pointing arrow presented to the left; typical Spatial Stroop or spatial congruency effect), whereas eye-gaze stimuli produced faster reaction times (RTs) when they were incongruent (e.g., a left looking eye-gaze stimulus presented to the right; which we refer to as the reversed Spatial Stroop or Reversed Congruency Effect; RCE). As stated by the authors (Marotta et al., 2018b), this dissociation is difficult to reconcile with the domain-general view of attentional processes and seems more coherent with the view that attention to gaze represents a unique attentional process that is qualitatively distinct from the attentional mechanisms engaged by biologically irrelevant stimuli. The congruency effect produced by arrows has been explained by the interference generated between the relevant spatial dimension of the target (the directionality of the arrow) and its irrelevant spatial dimension (the location in which the arrow is presented) (Kornblum et al., 1990; Luo & Proctor, 2013).

Although several explanations have been proposed to explain the RCE observed with eye-gaze stimuli, the eye-contact hypothesis is one of the most plausible hypotheses (Cañadas & Lupiáñez, 2012; Marotta et al., 2018b, 2019a). This hypothesis states that when, for example, a gaze stimulus is presented to the left, looking to the right (incongruent trial), it is looking towards the centre, at the location the participant is looking at, therefore potentially making visual contact with the participant. On the contrary, if the face appears on the left, looking to the left (congruent trial), it is looking away from the participant (averted gaze). According to Cañadas and Lupiáñez (2012) and Marotta et al. (2018), the eye-contact effect could explain the RCE, with faster RTs when the gaze is looking at you (incongruent trial) as compared to the situation of averted gaze (congruent trial). This social effect is not present when arrows are used as targets. Although this hypothesis has been used to explain these results in previous studies, the eye-contact hypothesis has not been directly tested (Cañadas & Lupiáñez, 2012; Marotta et al., 2018b). Alternatively, the RCE could also be explained by the motivational tendency to approach and/or to establish a social interaction during incongruent trials (direct gaze), while there is a motivational tendency to avoid the observer for congruent trials (averted gaze) (J. K. Hietanen et al., 2008). Another possible explanation suggests that on incongruent trials, the gaze is looking at the fixation point, at the same time that the participant is also orienting his/her gaze to the fixation point so that the participant and stimulus share the same object of attention, which would cause “joint attention”, facilitating the processing of the gaze on incongruent trials (Cañadas & Lupiáñez, 2012; Edwards et al., 2020). Furthermore, given that responses are also lateralized in this paradigm, the effect could also be due to some facilitation occurring in incongruent gaze trials, due to the incongruent gaze being perceived as looking at the correct response at the opposite side.

Moreover, it is well-known that social stimuli are often processed automatically and implicitly without much conscious effort (Lieberman, 2007), and the perception of gaze triggers automatic attentional orienting, even when the observer has neither the motivation nor the intention to direct his/her attention in that direction (Driver et al., 1999; see also Sato et al., 2007, 2016; Stein et al., 2011; Xu et al., 2011; Yokoyama et al., 2014). The eye-contact effect can occur implicitly, without much conscious effort, even when we do not intend to process direct gaze (Sato et al., 2007, 2016; Stein et al., 2011; Xu et al., 2018). However, to date, the eye-gaze direction has been used as a task-relevant dimension in all the studies investigating the spatial interference paradigm with faces and eyes (Cañadas & Lupiáñez, 2012; S. Jones, 2015; Marotta et al., 2018b; Torres-Marín et al., 2017), and the effect of the implicit or incidental processing of eye-gaze direction on the RCE has not been explored yet. It is still unknown whether and how eye-gaze direction can affect behaviour even when it is not task-relevant in spatial interference tasks. Therefore, in the present study, we intendedly used an implicit task in which direction was not task-relevant. If the eye-contact effect were responsible for the RCE observed with eye-gaze stimuli, this effect should be observed both in the explicit task (where the task-relevant dimension was the direction of the stimuli, eye-gaze or arrow) but also in the implicit task (where the relevant dimension was colour, while direction was completely irrelevant for the task). Supporting this idea, there is evidence showing that eye contact accelerates responses in a colour-discrimination task (J. K. Hietanen et al., 2016), and it is observed even in a detection task (Song et al., 2021; with lateralized faces or eyes), while gaze was completely irrelevant to the task (and participants did not even have to look at the faces or eyes). On the other hand, if no RCE were observed in the implicit task, the RCE could be entirely explained by the eye-contact hypothesis because eye contact should occur in this task, no matter whether the direction is or is not task-relevant. This is also theoretically important because the observation of a RCE only with explicit gaze processing would indicate the implication of mechanisms other than those involved in gaze cueing, which are observed with both implicit and explicit gaze processing (Sato et al., 2007).

Therefore, the aim of this study was to investigate the effect of implicit processing of eye-gaze direction on spatial interference effects in general and on the RCE in particular. This study is essential to elucidate the nature of the reverse congruency effect observed with eyes, and to further understand the boundary conditions in which eye-gaze direction can affect behaviour. In three experiments, we employed both explicit and implicit spatial interference tasks to test our hypothesis: if an eye-contact effect underlies the RCE with eye-gaze stimuli, this effect should be observed both in the explicit and implicit version of the task with eye-gaze stimuli, since eye contact should always occur, even when participants do not pay attention to stimuli direction or the processing of direction is incidental or implicit (Rothkirch et al., 2015; Sato et al., 2007; Stein et al., 2011; Xu et al., 2018; Yokoyama et al., 2014). For arrow stimuli, a typical congruency effect is expected in the explicit task, while no congruency effect is expected in the implicit task. In the latter, no interference is expected as the relevant dimension (colour) does not overlap with the two irrelevant spatial dimensions (location and directionality) (Kronblum 1990;Luo & Proctor, 2013).

6.3 EXPERIMENT 1

The goal of Experiment 1 was to replicate previous studies showing opposite congruency effects with eye-gaze and arrow stimuli (Cañadas & Lupiáñez, 2012; Marotta et al., 2018b) and to test whether the reversed congruency effect is still observed with eye-gaze stimuli when both space and direction are implicitly processed. To this aim, participants were required to identify the direction (explicit task), or the colour (implicit task) of both eyes-gaze and arrows, which were presented to either the left or right of the fixation point. Furthermore, the experiment was run as a pilot for a functional Magnetic Resonance Imaging (fMRI) study. Therefore, some parameters were changed from the original studies to adapt the procedure to fMRI.

Method

Participants

A total of 48 participants (4 men, mean age= 20.44, SD=2.67) from the Faculty of Psychology, University of Granada, participated voluntarily in the present experiment in exchange for course credit.

In Experiment 1, and the subsequent experiments, we estimated sample sizes based on previous research with the spatial interference paradigm. Marotta et al.'s (2018) study, which had enough statistical power to observe the critical effects (the interaction between Target Type and Congruency, and for each critical planned comparison), used a sample size of 36 participants. However, a posteriori sensitivity power analysis using G*power (Faul et al., 2007), showed that with a sample size of n = 48, the minimum effect size that could be detected for $\alpha = 0.5$, and $1 - \beta = 0.95$, for 2 groups and 4 within-participants conditions (for the critical Target Type x Congruency interaction) was $\eta^2 p$=0.04 (minimum detectable effect). Therefore, 24 participants per group were sufficient to observe the critical interaction (Target Type x Congruency), which effect size was larger than $\eta^2 p$=0.09 in both Experiments 1 and 3.

All participants were naive about the purpose of the experiment and reported having normal or corrected to normal vision. Signed informed consent was collected before the study, and participants were informed about their right to withdraw from the experiment at any time. The ethics committee from the University of Granada approved the experiments (175/CEIH/2017). Half of the participants (n=24) were randomly assigned to the explicit task, while the other half (n=24) were assigned to the implicit task.

Apparatus and stimuli

Stimulus presentation, timing, and data collection were controlled using E-Prime 2.0 (Schneider et al., 2002), ran on a standard Pentium 4 PC. Stimuli were presented on a 17” widescreen monitor with a 1,024 x 768-pixel resolution. All stimuli were presented on a white background. In each trial, a fixation point was presented at the centre of the screen. The target consisted of a 1.5 x 6.5 cm display of two arrows or two full cropped eyes, presented to either the left or right of the fixation point, and which could be either blue or brown (see Fig. 1). The distance from the fixation point to the centre of the lateral stimulus was 7 cm. Stimuli could be either blue or brown. Cropped eyes were obtained by manipulating the original stimuli from the NimStim Set of Facial Expressions (https://danlab.psychology.columbia.edu/content/nimstim-set-facial-expressions) with Adobe Photoshop CS.

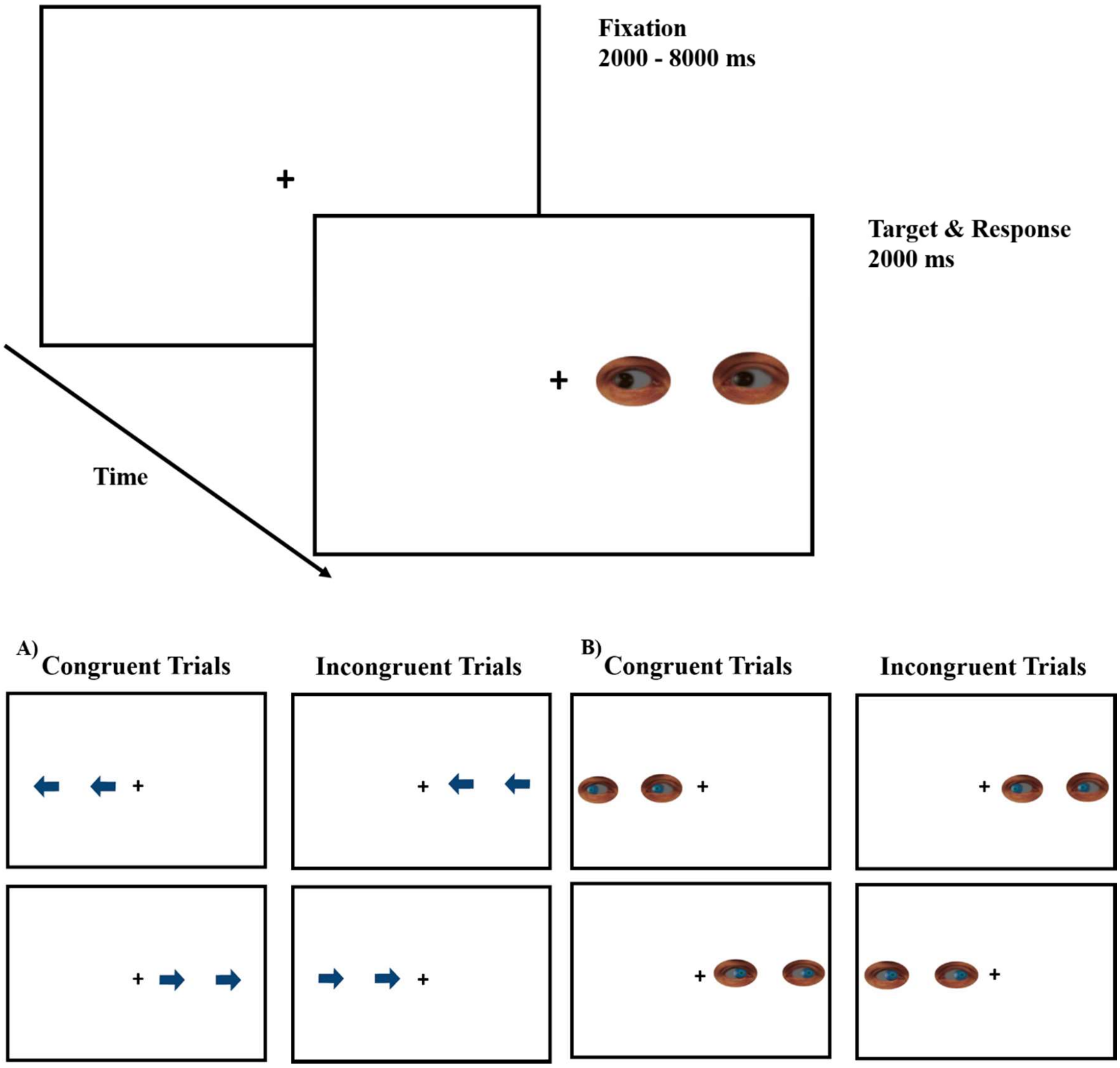

Fig.1 Schematic representation of the trial sequence of Experiment 1. In the example, an incongruent eye-gaze trial is represented. Bottom part: representation of all possible trials (congruent and incongruent with blue stimuli are represented, but stimuli could also be brown in colour) for A) arrows, and B) eye-gaze stimuli. The size of the eye-gaze stimuli has been increased to facilitate visibility, i.e. stimuli are not represented at scale

Procedure

Before starting the experiment, all participants provided their written informed consent to participate in the study. They sat at an approximate distance of 57 cm from the computer screen in a dark room.

The experiment consisted of two blocks of trials (one for each target type), each one composed of 15 practice trials followed by two experimental blocks of 64 trials each. The order of the two blocks was counterbalanced across participants. Since the experiment was designed for being a pilot fMRI study, the jitter fixation and the order of trial types were determined with an optimal sequencing programme designed to maximize the efficiency of recovery of the Blood-Oxygen-Level Dependent (BOLD) response (Optseq II). The jitter fixation periods were interleaved with the experimental trials as determined by the optimization programme.

Each trial started with a black fixation point for a random interval ranging from 2000- 8000ms (in 2000 ms steps). Participants were instructed to keep their eyes on the fixation point throughout the experiment. The target was then presented (two arrows or two eyes), for 2000 ms, pointing either to the right or to the left, and appearing either to the left or the right location.

In the explicit task, participants responded to the direction (left or right) the arrow or the eye-gaze stimulus was pointing at (by pressing either the “Z” –left, or the “M” –right, key on the QWERTY keyboard). In the implicit task, participants were asked to perform a colour-discrimination task by pressing one of the keys (“Z” or “M”) for blue stimuli and the other one for brown stimuli, depending on the counterbalanced condition. In both conditions, participants were instructed to respond as fast and accurately as possible within the 2000 ms of stimulus onset.

Design

A three-factor mixed design was used to analyse the data. Target type (arrow vs. eye-gaze) and Congruency (congruent vs. incongruent trials) were manipulated within participants, while Task (explicit vs. implicit) was manipulated between participants. For each participant, a total of 64 observations per experimental condition were considered. Practice trials were not analysed. Mean RTs and accuracy were calculated for each experimental condition and were used as dependent variables. Planned comparisons were used for the analysis of interactions.

Results

Trials with an incorrect response (3.22%), correct response trials with RTs faster than 200 ms (0 %) or slower than 1300 ms (1.38 %) (Marotta et al., 2018b), were considered anticipations and lapses, respectively, and were excluded from the RT analysis. Mean RTs and percentages of errors for each experimental condition are shown in Table 1.

Table 1 Mean correct RTs (in ms) and percentage of incorrect responses (IR) (with their corresponding standard deviations, SD), for each experimental condition of Experiment 1

		Arrow				**Eye-Gaze**			
		RT	**SD**	**%IR**	**SD**	**RT**	**SD**	**%IR**	**SD**
Explicit Task	**Congruent**	504	85	0.80	1.07	598	87	2.53	4.67
	Incongruent	535	76	3.84	4.22	584	81	3.70	3.25
Implicit Task	**Congruent**	615	100	2.75	2.25	642	97	2.40	2.17
	Incongruent	611	102	3.11	2.54	638	92	2.68	2.12

Mean RT data were submitted to a 2 (Task) x 2 (Target Type) × 2 (Congruency) mixed ANOVA, with Task (explicit vs. implicit) as a between-participant factor, and Target Type and Congruency as within-participants' factors. The analysis revealed a main effect of Target Type, F(1,46)= 93.32, MSE= 1248, p<.001, η^2p = 0.67, and a main effect of Task, F(1,46) = 7.92, MSE= 30785, p=.007, η^2p = 0.15. Shorter RTs were observed for arrows (566 ms) than eye gaze targets (616 ms), and for the explicit task (555ms) than the implicit task (627ms). The main effect of Congruency was not significant, F<1, but, critically, the interaction between Target Type and Congruency was significant, F(1,46)=14.55, MSE= 388, p<.001, η^2p = 0.24. The Target Type x Task and Congruency x Task interactions were also significant (respectively, F(1,46)= 18.88, MSE= 1248, p<.001, η^2p = 0.29 and F(1,46)= 5.53, MSE= 355, p=.023, η^2p = 0.11), showing larger effects of Target Type and Congruency for the explicit task than implicit task.

The critical three-way interaction between Target Type, Congruency, and Task was significant, F(1,46)= 16.12, MSE=388, p<.001, η^2p= 0.26, converging on the conclusion that the Interaction between Target Type and Congruency was modulated by the type of task. To explore this interaction further, separate ANOVAs were conducted for each task. The ANOVA for the Explicit Task revealed a significant Target Type x Congruency interaction, F(1,23)= 34.08, MSE= 349, p<.001, η^2p = 0.60. Planned comparisons showed that with arrow stimuli, RTs were significantly slower for incongruent (535 ms) than for congruent trials (504 ms) F(1,23)= 46.42, MSE= 244, p<.001, η^2p = 0.67. In contrast, for eye-gaze stimuli, RTs were significantly faster for incongruent (584 ms) than for congruent trials (598 ms), F(1,23)= 4.43, MSE= 513, p=.046, η^2p = 0.16 (the so-called RCE). In contrast, in the Implicit Task, the interaction between Target Type and Congruency was not significant F<1. Planned comparisons revealed no significant differences between congruent and incongruent trials neither with arrow stimuli, F<1, nor with eye-gaze stimuli, F<1 (Fig. 2).

The analysis of errors showed a main effect of Congruency, F(1,46)=11.54, MSE= 6 p=.001 η^2p=0.20, with more errors for incongruent (3.33%) than congruent trials (2.12%). No other main effect was significant (all Fs<1). The only significant interaction was Congruency x Task, F(1,46)= 6.28, MSE= 6, p=.016 η^2p=0.12. Neither the interaction between Target Type and Congruency (F(1,46)=2.51, MSE= 5 p=.12, η^2p=0.05), nor the Target Type x Congruency x Task interaction (F(1,46)=2.13, MSE= 5, p=.15, η^2p=0.04) were significant.

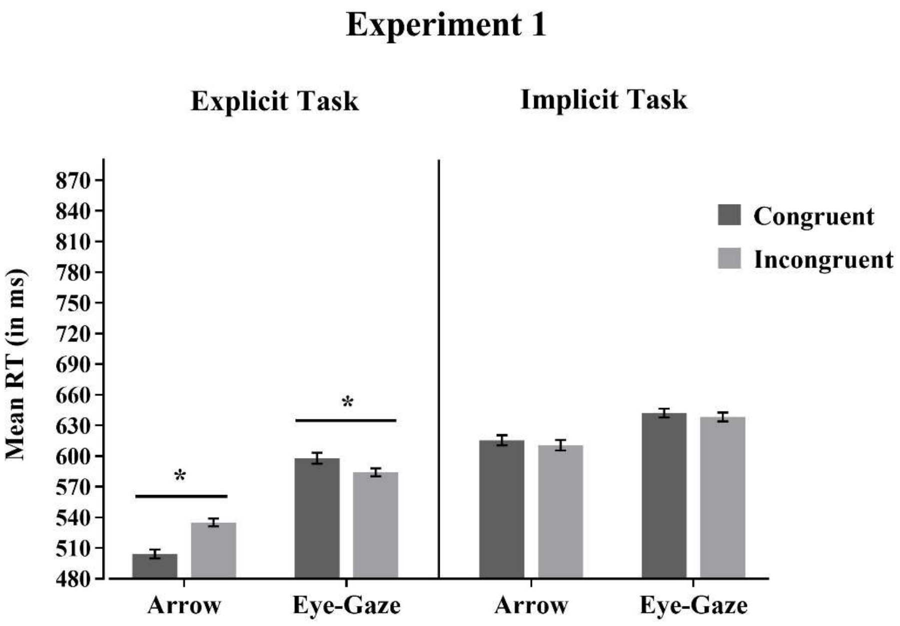

Fig.2 Mean RT for each Target Type, Congruency, and Task condition of Experiment 1. Asterisks represent statistically significant planned comparisons. Cousineau's method (2005) was used to calculate the standard errors of the means represented as error bars

Discussion

In this experiment, we explored whether the RCE observed with eye-gaze stimuli was also found even when the direction of stimuli was not relevant for the task. In the explicit task, in which participants were required to respond to the direction of stimuli (eye-gaze and arrows), we replicated the congruency effect with arrows and the RCE with eye-gaze stimuli (Marotta et al., 2018b). Whereas arrows elicited the typical spatial interference effect (i.e., faster RTs when their position was congruent with the direction the arrow was pointing at), eye-gaze produced a RCE (i.e., faster responses for incongruent as compared to congruent trials). According to Cañadas and Lupiáñez (2012) and Marotta, et al., (2018), the effect observed with eye-gaze stimuli in RTs can be explained by faster responses when eye contact is maintained.

Note that when eye-gaze trials were incongruent (i.e., when eye-gaze was presented on the right looking to the left), stimuli were looking at the centre, putatively favouring eye-contact with participants.

Moreover, as in Marotta et al., (2018), slower RT was observed with eye-gaze stimuli compared to arrows. This was probably due to the fact that eye-gaze stimuli are more difficult to process due to their social significance and/or perceptual complexity (J. K. Hietanen et al., 2006).

Importantly, no congruency effects were observed with either arrow or eye-gaze stimuli when a colour-discrimination task was required (implicit task). This finding suggests that, unlike what happens with gaze cueing paradigms (Sato et al., 2007), in the spatial interference paradigm, eye-gaze direction is not able to affect behaviour when it is implicitly processed. Therefore, these findings are not consistent with the eye-contact hypothesis since eye contact was not prevented in the implicit task, and nevertheless no RCE was observed. If the eye-contact occurred on incongruent trials, causing the RCE in the explicit task, it should have also occurred in the implicit task, because eye-contact also happened there.

Furthermore, although several studies have observed that eye-contact produces an increased attentional orienting, as well as more eye movements than averted gaze, even when the gaze is implicitly or subliminally processed (Chen & Yeh, 2012; Madipakkam et al., 2015; Stein et al., 2011), there is less evidence about whether and how eye-contact implicitly modulates social cognition. Some studies suggested different eye-contact functions with and without awareness in social decision-making (Luo et al., 2016) and on gaze cueing effects (Xu et al., 2018). A similar dissociation could also apply to the present study, explaining the different results observed between the explicit and the implicit conditions. However, further studies are necessary to shed light on this issue. Moreover, since no previous studies have explored the congruency effects with an implicit task, a replication seemed mandatory.

6. 4 EXPERIMENT 2

In the previous experiment, no congruency effects were observed when participants were required to discriminate the colour (implicit task) instead of the direction of the target (explicit task). However, Experiment 1 was, to the best of our knowledge, the first experiment that has ever assessed congruency effects elicited by eye-gaze and arrow stimuli by means of an implicit version of the spatial interference task. Therefore, it seems essential to replicate it with a different and larger sample. This was the primary purpose of Experiment 2. Moreover, it is important to note that in our previous experiment, the procedure, timing, and stimuli were adapted for piloting a future fMRI study, which could have influenced the observed pattern of results. For this reason, in Experiment 2, while some participants performed the implicit task with the same stimuli and procedure of Experiment 1, others performed the implicit task with a procedure and timing similar to the ones used in Marotta et al.'s (2018) study (see Method section for more details).

Method

Participants

A total sample of 76 participants (11 males, mean age= 20.20, SD= 2.36) from the Faculty of Psychology of the University of Granada participated voluntarily in the experiment in exchange for course credit. In Experiment 2a, twenty-four participants were tested using the same stimuli, timing, and procedure of the implicit task of Experiment 1 (using an identical sample size). In Experiment 2b, fifty-two participants were tested using a design with timing and procedure similar to Marotta et al.'s (2018). Given that a null result was expected in the implicit task, we increased sample size to acquire evidence in favour of the null or alternative hypothesis using Bayesian statistics. A sensitivity power analysis using G∗power (Faul et al., 2007) showed that with our final sample size (n = 76), the minimum effect size that could be detected for $\alpha = 0.5$, and $1 - \beta = 0.95$, for two groups and four within-participants conditions was $\eta^2 p = 0.028$ (minimum detectable effect).

Apparatus and stimuli

In Experiment 2a, apparatus and stimuli were identical to those used in the implicit task of Experiment 1. In Experiment 2b, apparatus and stimuli were the same, but stimuli were presented at an eccentricity of 8 cm (instead of 7 cm) from the fixation point.

Procedure

In Experiment 2a, the procedure and timing were identical to those of the implicit task of Experiment 1. In Experiment 2b, procedure and timing were adapted from Marotta et al.'s (2018) study. Practice trials had feedback for incorrect keypresses in the form of a 220Hz tone. Each trial started with a black fixation point presented in the centre of the screen for 1000 ms. The target (either two arrows or two eyes) was then presented for a fixed period of 1500 ms. As in the implicit task of Experiment 1 and Experiment 2a, target stimuli could be blue or brown randomly. Participants were asked to perform a colour-discrimination task by pressing as fast and accurately as possible one of the keys (“Z” or “M”) for blue stimuli and the other one for brown stimuli, depending on the counterbalance condition.

Design

In a preliminary analysis, the design consisted of a three-factor mixed measures design with the following factors: Experiment (2a and 2b), Target type (arrow and eye-gaze), and Congruency (congruent and incongruent). However, since the main effect of Experiment or its interaction with other variables was not significant (all ps>.09, with the three-way Target Type x Congruency x Experiment interaction far from significance, F<1), this factor was eliminated from the remaining analyses. Therefore, we used the same design of the implicit condition of Experiment 1.

Results

As in Marotta et al., (2018), trials with RTs faster than 200 ms (0.01%) or slower than 1300 ms (0.99%) as well as incorrect responses (3.74%) were excluded from the RT analysis. Table 2 shows the mean (and standard deviation) for RTs and percentages of errors for each experimental condition.

Table 2 Mean correct RTs (in ms) and percentage of incorrect responses (IR) (with the corresponding standard deviations SD) for each experimental condition of Experiment 2

		Arrow				**Eye-Gaze**			
		RT	**SD**	**%IR**	**SD**	**RT**	**SD**	**%IR**	**SD**
Implicit Task	**Congruent**	600	85	3.34	3.72	636	73	2.97	3.35
	Incongruent	603	80	3.38	3.16	634	76	2.94	2.85

Mean RT data were submitted to 2 (Target Type) × 2 (Congruency) repeated measure ANOVA. The analysis of the mean RTs again revealed a main effect of Target Type F(1,75)= 52.15, MSE= 1698, p<.001, $\eta^2 p$ = 0.41, with shorter RTs for arrow targets (601 ms) than for eye-gaze targets (635 ms). The main effect of Congruency, and the Target Type x Congruency interaction were not significant, F<1 and F(1,75)=1.52, MSE= 326, p=.222, $\eta^2 p$ = 0.02, respectively. Planned comparisons confirmed that there were no significant differences between congruent and incongruent trials neither with arrow stimuli, F(1,75)=1.06, MSE= 348, p=.304, $\eta^2 p$ = 0.01, nor with eye-gaze stimuli, F<1 (see Fig. 3).

In the analysis of errors, neither the main effects nor the interaction were significant (all ps>.17).

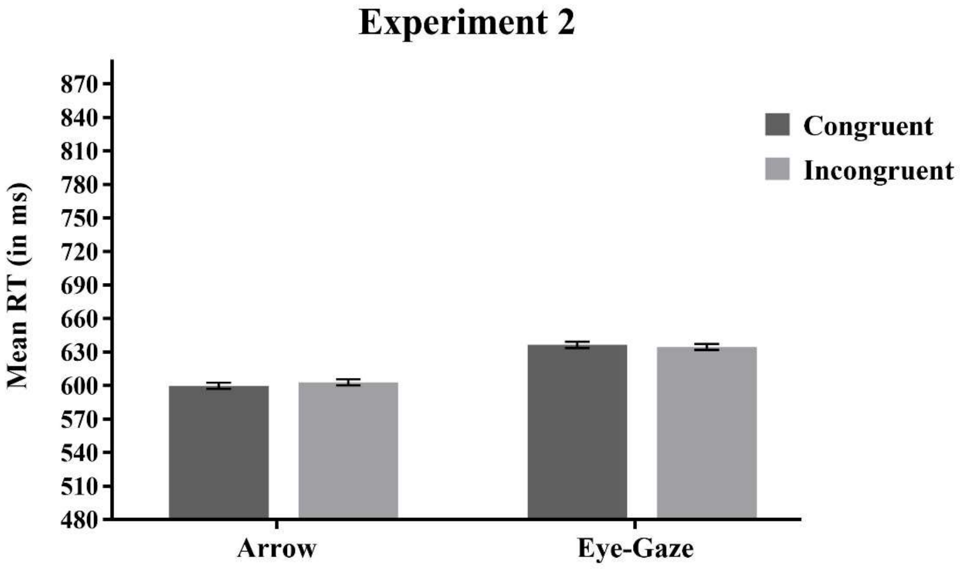

Fig.3 Mean RT for each Target Type and Congruency condition of Experiment 2. Cousineau's method (2005) was used to calculate the standard errors of the means represented as error bars

Combined Analysis of Experiments 1 and 2

This section presents a combined analysis of the implicit task of Experiment 1 and Experiment 2 (N=100) to check and confirm the absence of congruency effects for the implicit task.

Mean correct RTs were submitted to a two-factor repeated measures design with Target Type (arrows and eye-gaze) and Congruency (congruent and incongruent) as within-participants' factors. As reported above, Experiment did not modulate participants' performance, and therefore, it was not included as a factor in the combined analyses (all ps>.12).

Moreover, the combined analysis was also performed with Bayesian statistics to check for evidence in favour of either the null hypothesis (evidence for no main effect of congruency or no interaction between Target Type and

Congruency). In Bayesian statistics, analyses are not biased against the null hypothesis. They allow quantifying how much the gathered evidence (i.e., the observed data) supports either the presence or the absence of an effect. Therefore, on the basis of Bayesian statistics, we can conclude whether the alternative hypothesis is more probable than the null hypothesis or vice versa. Following Wagenmakers et al. (2018), a $BF_{10} = 1$ indicates no evidence favouring the alternative hypothesis (H1) or the null hypothesis (H0). $BF_{10} > 1$ indicate evidence in favour of H1: 1–3 anecdotal evidence, 3–10 moderate evidence, 10–30 strong evidence. $BF_{10} < 1$ indicate evidence in favour of H0: 0.33–1 anecdotal evidence, 0.10–0.33 moderate evidence, 0.03–0.10 strong evidence. Output effects for the main effects and interactions in the Bayesian ANOVAs are presented across matched models, following Wagenmakers et al. (2018) recommendations for Bayesian analyses in JASP.

The analysis showed one more time a main effect of Target Type, $F(1,99)= 65.15$, $MSE= 1615$, $p<.001$, $\eta^2 p = 0.40$, $BF_{inclusion} = 3.03852e+23$. The main effect of Congruency and the interaction between Target Type and Congruency were not significant (both $Fs<1$; $BF_{inclusion}= 0.11$ and $BF_{inclusion}=0.19$, respectively). The analysis of the interaction revealed no significant differences between congruent and incongruent trials neither with arrows, $F<1$, $BF_{10}= 0.16$, nor with eye-gaze stimuli, $F(1,99)= 1.13$, $MSE= 255$, $p=.29$, $\eta^2 p = 0.01$, $BF_{10} = 0.25$. These analyses demonstrate that there is moderate evidence in favour of an absence of congruency effects for both arrow and eye gaze stimuli for the implicit task.

We further explored whether the main effect of Congruency, or the Congruency x Target Type interaction were observed in the implicit task while equating response conditions between the implicit and the explicit task. Note that while in the explicit task (in Experiment 1 and in Marotta, et al., 2018) there is always a compatible mapping between the target direction and the response location (e.g., an eye-gaze/arrow indicating left always required a left response), in the implicit task participants were required to respond to the target colour independently from its direction and consequently keypresses responses could be consistent or not with target direction, i.e., a compatible mapping response was only required for the 50% of trials. As such, it is unclear whether the lack of Target Type x Congruency interaction observed in the implicit task condition was due to the implicit nature of the task or to the between tasks differences in response mapping. Indeed, it is possible that congruency effects are only present when the response mapping is compatible. To test for this possibility, we performed an ANOVA considering the response mapping as a factor in the combined analysis with 100 participants.

The analysis showed one more time a main effect of Target Type, F(1,99)= 65.15, MSE= 3231, p<.001, η^2p = 0.40. The main effect of Congruency was not significant, F<1. However, the main effect of Response Mapping was significant, F(1,99)= 10.56, MSE= 701, p=.002, η^2p = 0.10, with faster responses for compatible (617 ms) than incompatible mapping response trials (623 ms). Neither the interaction between Target Type x Congruency, nor Target Type x Response Mapping were significant, both Fs<1. Furthermore, and importantly for our research aims, the critical three-way Target Type x Congruency x Response Mapping interaction was not significant, F(1,99) = 1.07, MSE=630, p=.30, η^2p =0.01.

Interestingly, the Congruency x Response Mapping interaction was significant, F(1,99)=4.05, MSE= 1223, p=.047, $\eta^2 p$ =0.04, revealing no significant differences between congruent (615 ms) and incongruent trials (619 ms) on compatible response mapping trials, F(1,99)=1,63, MSE=587, p=.20, $\eta^2 p$ =0.02. In contrast, for incompatible response mapping trials RTs were significantly faster for incongruent (621 ms) than for congruent trials (626 ms), F(1,99)= 4,85, MSE=319, p=.03, $\eta^2 p$ =0.05. This interaction can be easily explained by the fact that, while in the compatible mapping congruent trials are responded with the ipsilateral response and incongruent trials with the contralateral one, the opposite is true for the incompatible response mapping. So, this interaction, refer to a main Simon effect.

Indeed, when Simon laterality was considered in the analysis instead of Response Mapping, a main effect of Simon laterality was observed, F(1,99)= 4.05, MSE= 1223, p=.047, $\eta^2 p$ = 0.04, with faster responses for ipsilateral (618 ms) than contralateral trials (623 ms). Again, and importantly, neither the Target Type x Congruency, nor the Target Type x Simon interaction or the three-way interaction were significant, all Fs≤1. The Congruency x Simon interaction was significant, F(1,99)=10.56, MSE= 701, p=.002, $\eta^2 p$ =0.1, revealing significant differences between congruent (615 ms) and incongruent trials (621 ms) in ipsilateral trials, F(1,99)=4.14, MSE=364,p=.04, $\eta^2 p$ =0.04. For contralateral trials the opposite was true, RTs were significantly faster for incongruent (619 ms) than for congruent trials (626 ms), F(1,99)= 7.92, MSE=281, p=.006, $\eta^2 p$ =0.07. Again, this interaction represents the main effect of Response Mapping. Importantly, these analyses show that, although significant effects of Response Mapping and Simon laterality are observed when correspondingly analysed, they do not modulate neither the main effect of Congruency nor the critical Congruency x Target Type interaction.

Moreover, it is known that the response compatibility of the preceding trial affects the response mapping effect of the subsequent trial, with stronger effects following a preceding compatible than following a preceding incompatible trial. Therefore, a fairer test for the implicit task should restrict the analyses to the compatible response mapping trials, also preceded by another compatible response mapping trial, as this would mimic the conditions in the explicit task even better. To explore this issue, we reanalyzed the data filtering only trials in which a compatible response mapping was used in the current and the previous trial. Results revealed a non-significant, although marginal, Target Type x Congruency interaction, F(1,99)=3.11, MSE=1487, p=.08, η^2p =0.03. To further explore this issue, although being aware that the number of trials per condition is much reduced (average of 7,54 trials per experimental condition, ranging from 2 to 19), we reanalyzed the data only considering the trials with compatible response mapping on both the two previous trials and the current trial. Results now revealed a significant interaction between Target Type and Congruency, F(1,99)=4.15, MSE=2328, p=.044, η^2p =0.04, although the analysis of the interaction revealed no significant differences between congruent and incongruent trials neither with arrows (congruent: 588 ms, incongruent: 595 ms) nor with eye-gaze stimuli (congruent: 643 ms, incongruent: 630 ms).

Discussion

Experiment 2 confirmed the absence of congruency effects in the implicit task when the direction of both arrow and eye-gaze stimuli was irrelevant for the task. This was true even when the same parameters of the original task (Marotta, et al., 2018) were used. Indeed, the congruency effect was not modulated by the timing manipulation, size of the stimuli, or eccentricity. The absence of congruency effects in the implicit task suggests that the direction of both arrows and eye-gaze stimuli do not affect behaviour when it is implicitly processed in the spatial interference paradigm.

Nevertheless, an alternative explanation for the absence of congruency effects in the implicit task with both targets (arrow and eye-gaze) may be related to the task differences in response mapping. It is important to note that while in the explicit task there was always a compatible mapping between the target direction and the response location (e.g., an eye-gaze/arrow indicating left always required a left response), in the implicit tasks a compatible response mapping was only required in 50% of the trials. To explore this issue, we reanalyzed the data, considering the response mapping as a factor in the combined analysis. Although results demonstrated an effect of response mapping, with faster responses for compatible than incompatible response mapping trials, this effect did not modulate the crucial interaction between Target Type and Congruency, demonstrating that this effect was not different between eye-gaze and arrow stimuli. Therefore, the response mapping variable does not appears to be critical for the difference observed in the congruency effect between the two stimuli. Moreover, when we restricted the analysis to compatible response mapping preceded by compatible response mapping trials to mimic in the implicit task the scenario of the explicit task, the data are along the same lines; there is no interaction between Congruency and Target type. Only if we accumulate several compatible mapping response trials in a row do we find such a significant interaction (Target type x Congruency), which could be related to the task set implicitly induced by the repeated compatible response mapping. However, this is highly speculative and the analysis were not completely reliable, as there were not enough trials to properly explore this issue.

Similarly, when laterality of responses was instead considered in the analyses, a significant Simon effect was observed in the implicit task, with faster responses when stimulus location and response location matched, although again the effect was not modulated by Target type, which might contradict previous studies finding a "gaze direction Simon effect" (Zorzi et al., 2003). In any case, it is difficult to conclude whether or not the Simon or Response Mapping effects are implicated in the results observed with the implicit task, regarding the lack of a congruency effect.

Therefore, to more directly rule out the possibility that motor components are responsible for the difference in congruency effects observed between the explicit and implicit tasks, in Experiment 3, rather than controlling for, we decided to eliminate laterality of responses in both tasks. Thus, verbal (instead of manual) responses were required for both the implicit and explicit spatial interference tasks.

6.5 EXPERIMENT 3

Experiment 3 was conducted to control for the possibility that manual motor components were responsible for the differences in the congruency effect observed between explicit and implicit tasks and to replicate the main findings obtained in the previous experiments. This experiment replicated Experiment 1, except that participants were required to respond verbally instead of manually. In particular, Experiment 3A consisted of a verbal explicit task, in which participants verbally reported the direction of the stimuli, and Experiment 3B consisted of a verbal implicit task, in which participants verbally reported the colour of the stimuli.

Method

Participants

A new sample of 50 participants (13 males, mean age= 21.62, SD= 3.53) from the Faculty of Psychology of the University of Granada participated voluntarily in the experiments in exchange for course credit. Twenty-five participants took part in Experiment 3A, and twenty-five different participants in Experiment 3B.

Apparatus and stimuli

Apparatus and stimuli were identical to those used in Experiment 1, except for the use of a soundbox for response collection (RTs). The soundbox collected RT, using an ATR 20 microphone with low impedance connected to a Serial Response Box (Psychology Software Tools, Schneider, (1995). The accuracy of the response was manually collected by the researcher using a keyboard.

Procedure

In Experiment 3A and 3B, the task was identical to Experiment 1, except for the instructions and response type. In Experiment 3A, participants were required to perform a direction discrimination task by verbally reporting the direction the stimulus was pointing at (i.e., by saying aloud either “Izquierda” -left- or “Derecha” -right-). In Experiment 3B, participants were asked to perform a colour-discrimination task by verbally reporting the colour of the target. In both experiments, the researcher was in the room with the participant to categorize the response given by the participants.

Design

The design was the same as in Experiment 1. Although participants were not randomly assigned to the two experiments, and therefore the explicit and implicit conditions were run as different experiments rather than as between-participants experimental conditions, for the sake of similarity with the analyses performed in Experiment 1, we performed a 3-factor mixed ANOVA, with Task (explicit vs. implicit) as a between-participants factor, and Target Type and Congruency as within-participants factors. Then, a different Target Type X Congruency ANOVA was conducted on the data from each experiment, Experiment 3A: Explicit Task and Experiment 3B: Implicit Task.

Results

Trials in which the microphone did not correctly record participants' responses (2.13% for Exp. 3A, and 3.72% for Exp. 3B), trials with an incorrect response (2.12% for Exp. 3A, and 1.15% for Exp. 3B) and correct response trials with RTs below 200 ms (0.03% for Exp. 3A, and 0.00% for Exp. 3B) or above 1300 ms (0.95% for Exp. 3A, and 0.31% for Exp. 3B) were excluded from the RT analysis. Mean (and standard deviation) for RTs and percentages of errors (% IR) for each experimental condition are shown in Table 3.

As in Experiment 1, the analysis revealed a main effect of Target Type, F(1,48)= 61.80, MSE= 1300, p<.001, $\eta^2 p$ = 0.56, and a main effect of Task, F(1,48) = 47.68, MSE= 22069, p<.001, $\eta^2 p$ = 0.50. The critical three-way interaction between

Target Type, Congruency, and Task was significant, F (1, 48)= 18.30, MSE=187, p<.001, η^2p= 0.28, suggesting that the Target Type x Congruency interaction was modulated by the Type of Task. Then a different Target Type X Congruency ANOVA was conducted on the data from each experiment (explicit and implicit tasks).

Experiment 3A: Explicit Verbal Task

The analysis revealed a main effect of Target Type, F(1,24)= 48.48, MSE= 1785, p<.001, $\eta^2 p$ = 0.67, showing faster RTs for arrow targets (773 ms) compared to eye gaze targets (832 ms). The main effect of Congruency was not significant, F<1. The Target Type x Congruency interaction was significant (F(1,24)= 20.72, MSE= 269, p<.001, $\eta^2 p$ = 0.46). Planned comparisons showed that with arrow stimuli, RTs were significantly slower for incongruent (782 ms) than for congruent trials (765 ms) F(1,24)= 15.60, MSE= 213, p<.001, $\eta^2 p$ = 0.39. In contrast, for eye-gaze stimuli, RTs were significantly faster for incongruent (825 ms) than for congruent trials (839 ms), F(1,24)= 5.55, MSE= 415, p=.027, $\eta^2 p$ = 0.19 (see Fig. 4).

The analysis of errors showed a main effect of Target Type, F(1,24)=8.73, MSE=3, p=.007 $\eta^2 p$=0.27, with more errors for eye-gaze (2.58%) than arrow trials (1.63%). The main effect of Congruency was significant, F(1,24)=4.75, MSE=3, p=.039 $\eta^2 p$=0.17, with more errors for incongruent (2.49%) than congruent trials (1.72%). The interaction between Target Type and Congruency was not significant, F<1. Planned comparisons revealed no significant differences between congruent and incongruent trials neither with arrow stimuli nor with eye-gaze stimuli (ps>.11).

Table 3 Mean correct RTs (in ms) and percentage of incorrect responses (IR) (with the corresponding standard deviations -SD-, in parentheses) for each experimental condition in Explicit Verbal Task (Exp. 3A) and Implicit Verbal Task (Exp. 3B)

		Arrow				**Eye-Gaze**			
		RT	**SD**	**%IR**	**SD**	**RT**	**SD**	**%IR**	**SD**
Explicit Verbal Task	**Congruent**	765	85	1.33	1.87	839	90	2.12	1.83
	Incongruent	782	85	1.94	2.47	825	76	3.04	2.50
Implicit Verbal Task	**Congruent**	649	79	1.19	1.43	669	60	1.25	1.59
	Incongruent	645	76	1.24	1.44	668	60	0.96	1.22

Experiment 3B: Implicit Verbal Task

The analysis also revealed a main effect of Target Type, F(1,24)= 13.96, MSE=814, p=.001, η^2p = 0.37, showing faster RTs for arrow targets (647 ms) compared to eye gaze targets (668 ms). Neither the main effect of Congruency nor the interaction between Target Type and Congruency were significant (F(1,24)= 1.01, MSE= 104, p=.325, η^2p = 0.04 and F<1, respectively). Planned comparisons revealed no significant differences between congruent and incongruent trials neither for arrow nor for eye gaze stimuli (both ps>.17) (see Fig. 4).

In the analysis of errors, neither the main effects nor the interaction were significant (all ps>.53).

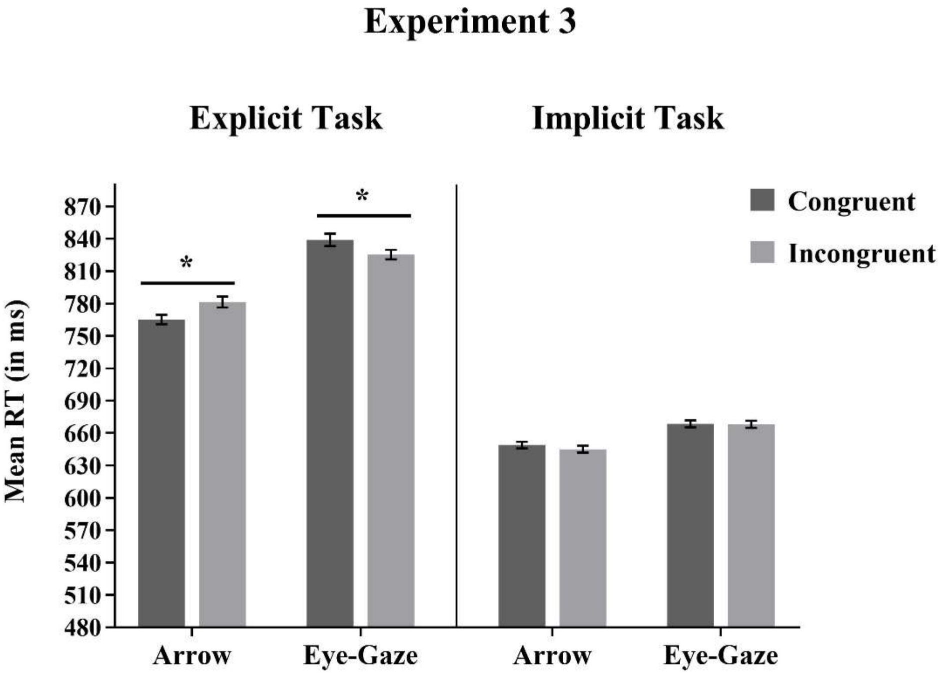

Fig.4 Mean RT for each Target Type and Congruency condition for Experiment 3A (Explicit Verbal Task) and 3B (Implicit Verbal Task). Asterisks represent statistically significant planned comparisons. Cousineau's method (2005) was used to calculate the standard errors of the means represented as error bars

Discussion

Experiment 3 replicated all the crucial findings of Experiment 1. In particular, when participants were required to verbally respond to the direction of the stimuli (Experiment 3A), standard congruency effects and RCE were observed for arrows and eye-gaze stimuli, respectively. On the other hand, when participants were required to verbally report the colour of the stimuli (Experiment 3B), no congruency effects were observed with either arrow or eye-gaze stimuli, as in the implicit task of Experiments 1 and 2. Since, in the present experiment, responses were verbal instead of manual, these findings suggest that the dissociation between the explicit and implicit task observed in Experiment 1 was due to differences in the way target direction is processed in explicit and implicit tasks rather than to the different manual motor components implicated in the tasks. In order words, differences in spatial congruency effects between explicit and implicit tasks are still observed even in the absence of a lateralized motor response.

Interestingly, although the findings of Experiment 1 were replicated in Experiment 3, overall RT was slower for Experiment 3 than Experiment 1. This suggests that the response modality employed, in this case, verbal response, affects overall RTs in different ways. It has been demonstrated that verbal response interference excess manual response interference (Augustinova et al., 2019; MacLeod, 1991). Furthermore, in Experiment 3, RT was slower for the explicit than the implicit task in contrast with Experiment 1, in which RT was faster for the explicit than the implicit task. Perhaps the lateralized manual response helped performance in the explicit task, when participants were to respond with a natural mapping to the direction of stimuli, but not when they had to arbitrarily categorize colours with left and right responses. In contrast, naming colour might be more natural than naming left-right lateralized responses, thus explaining the main effect of the task in Experiment 3. In any case, given that the RCE observed with gaze was not affected by the manual vs. verbal response, results reinforce the idea that this specific effect of gaze is not related to response factors. Furthermore, results suggest that the fact that congruency effects are only observed with the explicit task cannot be associated with any possible slowdown in RT in the implicit task as observed in Experiments 1 and 2.

6.6 General discussion

In the reported experiments, we examined whether the implicit or incidental processing of gaze and arrows direction can modulate spatial interference effects in general, and the RCE observed with gaze in particular. To this aim, explicit and implicit variants of a spatial interference task were used. In the explicit variant, the direction of the stimuli (eye-gaze or arrows), either congruent or incongruent with their spatial position, was the task-relevant dimension. In the implicit variant, the task-relevant dimension was their colour (blue or brown), a spatially irrelevant dimension.

We observed that responses were, in general, slower for gaze than for arrow stimuli (J. K. Hietanen et al., 2006; Vlamings et al., 2005). This may have been due to the social meaning and perceptual complexity of eye-gaze stimuli, which may produce larger attentional capture (Marotta et al., 2018). Supporting the idea that eye-gaze stimuli are special because of their social meaning, Cañadas and Lupiáñez (2012) showed that when triangles or symbolic eyes were used as stimuli, no differences between eye gaze and arrows were found.

Nevertheless, the most important result was the dissociation between the congruency effects observed for arrows and gaze with explicit vs. implicit tasks. When participants were required to respond to the direction of the target stimuli (explicit task), arrows elicited the typical spatial interference effect (i.e., faster RTs when their position was congruent with the direction the arrow was pointing at). According to Luo & Proctor (2013), in the classical Stroop effect or spatial interference effect, the location of stimuli (irrelevant dimension) interferes with their directionality (relevant dimension) creating the spatial congruency effect. In contrast, eye-gaze stimuli produced a RCE (i.e., faster responses for incongruent as compared to congruent trials). This replicates previous findings (Cañadas & Lupiáñez, 2012; S. Jones, 2015; Marotta et al., 2018b, 2019a; Torres-Marín et al., 2017) and supports the view according to which attention to eye-gaze may represent a unique attentional process and reflect the operation of a specialized cognitive mechanism (Farroni et al., 2002). On the other hand, when participants were required to respond to the colour of stimuli (implicit task), no congruency effects were observed with either arrows or eye-gaze.

One possible explanation about the lack of congruency effect in the implicit variant of the task could be related to the type of spatial interference paradigm. When participants are required to discriminate another dimension of the stimulus (i.e., the colour), different from the spatial dimension, the congruency effects associated with the spatial interference task could be unaffected, since space is task-irrelevant. Luo and Proctor (2013) proposed that in interference tasks (such as Stroop and Simon), the irrelevant stimulus dimension disturbs performance only when it overlaps with the relevant stimulus dimension. In the implicit task used in the present research, there was a non-spatial dimension (colour) and two spatial dimensions (spatial location and direction of stimuli). The non-spatial dimension and the two spatial dimensions are assumed to be processed by separate systems, each of which operates on its own codes. Therefore, it is possible that the interference effect completely disappeared for both types of stimuli (arrow and eye-gaze) because of the lack of dimensions overlap (Luo & Proctor, 2013; Pang et al., 2020).

Another interpretation is also possible: although the arrow/gaze direction and location dimensions are irrelevant to the task, they could interfere with the lateralized response in 50% of the trials. Therefore, participants might try to inhibit the response to avoid interference. This could have eliminated spatial interference in the implicit task of Experiments 1 and 2. However, this interpretation cannot explain the pattern of results observed in Experiment 3, where responses were not lateralized, and therefore arrow/gaze direction or location should not interfere with responses. Furthermore, we observed typical Simon and Response Mapping compatibility effects for both the arrow and gaze stimuli, which indicates that spatial dimensions could not be completely inhibited. Interestingly, a tendency for a spatial congruency effect was observed in the implicit task when we only considered trials mirroring the compatible mapping of the explicit task. Therefore, the compatible mapping might have incidentally drawn attention to the direction of the stimuli (always in the explicit task, and on the consecutively compatible trials in the implicit one). Thus, some attention to the direction dimension seems to be necessary for the spatial congruency effect to occurs, no matter whether attention is drawn explicitly or implicitly.

It could be argued that with a more elaborated and more ecological social context, like when presenting the whole faces as in Cañadas and Lupiáñez (2012), the RCE would have been observed even at an implicit level. However, this is not a simple issue. Apart from whole faces being more ecological than cropped eyes, the RCE has been observed to be larger with whole faces than with eyes in explicit tasks, where the direction is relevant to the response (Cañadas & Lupiáñez, 2012). However, this might be for a different reason. As shown by Román-Caballero et al., (2021a, 2021b), this could be due to the fact that the Simon effect, which is present for both arrows and gaze, is eliminated when the targets (either arrows or eyes) are surrounded by a complex background, i.e., the whole face, from which they need to be segregated. The cropped eye stimuli are the same from the whole face, and therefore we consider that the same result would be observed with whole faces (i.e., no implicit RCE) as similar effects are observed for cropped eyes and whole faces when the effect of the background is taken into account (see Román-Caballero et al., 2021b).

In any case, the implicit task used in this study was a tool to test the eye-contact hypothesis, since the same eye-contact should still occur on incongruent trials even if participants are responding to a non-spatial dimension. Indeed, previous studies have observed that eye-contact also occurs when gaze is incidentally processed (Adolphs, 2009; Lieberman, 2007; Sato et al., 2016; Stein et al., 2011; Xu et al., 2011). Moreover, the eye-contact effect is observed in detection tasks (Song et al., 2021; lateralized faces or eyes) and in colour-discrimination tasks (see Hietanen et al., 2016) when gaze direction is completely irrelevant to the task. However, our results clearly show that the RCE is not observed when participants do not respond to gaze direction (in spite of paying attention to the eyes, and using the same parameters and stimuli than when a clear RCE is observed in the explicit task). We can therefore conclude that either: a) No eye-contact occurs, when gaze direction is irrelevant, in the exact stimuli conditions in which a RCE occurs when gaze direction is relevant, or b) eye contact does occur but it does not affect responses as to produce the RCE. In any case, no matter whether either a) or b) is true, the eye-contact hypothesis of the RCE proposed by Cañadas and Lupiáñez (2012) and Marotta et al. (2018) is refuted.

Moreover, the dissociation in the congruency effect in the explicit and implicit tasks was observed with both manual (Experiment 1 and 2) and verbal (Experiment 3) responses. We hypothesized that response mapping might have influenced the outcome of the study and, thus, our understanding of the results. For example, the difference in congruency effects observed between explicit and implicit tasks might be related to the different mapping of responses. Indeed, while in the explicit task, there was always a compatible mapping between the target direction and the response location (e.g., an eye-gaze/arrow indicating left always required a left response), in the implicit task, response mapping was arbitrary. Therefore, a compatible response mapping was only required for 50% of trials. However, the combined analysis of Experiment 1 and 2 considering response mapping as a factor showed that the effect of response mapping was the same independently of the type of the stimuli (arrow or eye-gaze) used and therefore it was not able to explain the RCE observed for eye-gaze stimuli. In addition, the fact that the same dissociation between implicit and explicit tasks was observed with both manual and verbal responses suggests that this dissociation is due to actual differences in the way target direction is processed in explicit vs. implicit tasks rather than to different manual motor components implicated in these two tasks. Therefore, all explanations of the eye-gaze RCE that lay on response lateralization factors are refuted by this finding.

An alternative explanation to the eye-contact hypothesis might be that the RCE observed with eye-gaze stimuli is related to the fact that the gaze can lead to an approach or avoidance of social behaviour. In incongruent trials, gaze direction may be interpreted as a social approach, while in congruent trials, it may be interpreted as a situation of social distancing or avoidance. This may respectively lead to more or less engagement to the task (J. K. Hietanen, 2018; J. K. Hietanen et al., 2008). However, the results of the implicit task do not seem to support this explanation. Indeed, when participants had to discriminate another characteristic of the target, although eye-contact or approach behaviour is maintained, no RCE was observed.

Yet another different explanation is related to the joint attention behaviour (Cañadas & Lupiáñez, 2012; Edwards et al., 2020; Mundy, 2018). It could be argued that participants and the eye-gaze stimulus share the same focus of attention (i.e., fixation point) when an incongruent trial is presented (like in the example of Figure 1), consequently facilitating the processing of the gaze. In congruent trials, however, eye-gaze is averted away from the central point of mutual attention, looking at out of the task. Therefore, in congruent trials, it is possible that our attention and eyes are moved outside the task, causing what might be called “joint distraction”, i.e., drawing attention outside of the task and therefore increasing RTs (see Hemmerich et al., 2021, for an extended explanation of this hypothesis).

The three explanations described above explain the RCE (eye-contact, approach/avoidance, and joint attention/joint distraction) share characteristics related to the social properties of eye-gaze stimuli. Although there are indeed some commonalities between the three explanations, it is also important to acknowledge that there are different social modulators of eye-gaze stimuli that might lead to different levels of processing of gaze and therefore to different effects on human visual attention that need to be understood and investigated (Dalmaso et al., 2020b). According to the literature, eye-contact (Chen & Yeh, 2012; Rothkirch et al., 2015; Stein et al., 2011) and approach-avoidance motivational theory (Elliot, 2006; Reichardt, 2018) can occur even in implicit tasks, as their effect is a rapid and automatic response, which does not require explicit attentional behaviour towards the stimulus to generate a response (J. K. Hietanen, 2018). Therefore, if these explanations underlined the RCE, the same results would have occurred in both implicit and explicit tasks. Then, only the joint attention/joint distraction explanation would remain as a potential explanation, as explicit processing of gaze direction seems to be an important condition for generating the RCE. Both joint attention/joint distraction would require developing gaze intention, even if automatically, and the following of gaze in a particular direction, which can happen automatically in explicit tasks.

In the case of gaze cueing tasks, in which participants must respond to a lateralized object, the presentation of a face at fixation benefits processing of gazed-at objects, even if the gaze is non-predictive and completely irrelevant for the task. However, as described above, similar cueing effects are observed for gaze and arrows (Brignani et al., 2009), even if gaze cueing effects have been attributed to joint attention (Kawai, 2011; Xu et al., 2011). The fact that gaze cueing seems to occur with implicit processing of gaze, whereas for the RCE explicit processing of gaze direction is necessary, would indicate that different mechanisms underlie the two effects. The presence of the lateralized object might incidentally activate processing of gaze direction in the gaze cueing paradigm, whereas in the spatial interference paradigm, gaze direction is only intentionally activated when it is task-relevant. Although Edwards et al. (2020) have attributed the RCE to joint attention, i.e., the beneficial effect of both the participant and the gaze to look at the fixation point in incongruent trials, Aranda-Martín et al. (2022) have recently shown that the RCE does not appear until late childhood, in spite of joint attention being fully developed much earlier (Mundy et al., 2007). This would leave "joint distraction" (Klara Hemmerich et al., 2021) as the more likely explanation of the RCE.

This “joint distraction” or whatever mechanism is producing the RCE, would be exclusive of gaze, in contrast to other orienting mechanisms, also present in gaze, but shared with nonsocial stimuli like arrows, as observed with gaze cueing paradigms (Bonmassar et al., 2019; Brignani et al., 2009). Therefore, gaze seems to trigger domain-general and domain-specific orienting mechanisms. The results of a recent ERP study from our laboratory with the same spatial interference paradigm seems to support this claim. Indeed, we observed comparable congruency modulations for both eye-gaze and arrows stimuli at early stages of processing (P1, N1, and N170; i.e., domain-general effect) and later dissociations (N2 and P3; i.e., domain-specific effect) according to the type of target (Marotta et al., 2019a). This may suggest that the initial attention and perceptual stages of stimuli processing (maybe related to automatic mechanisms) are similar for gaze and arrows, while later stages (maybe related to the controlled aspects of social attention) differ according to the type of the stimulus used (Capozzi & Ristic, 2020).

To sum up, the results of this work can be summarized in some key contributions. First, we replicated the findings in which in the context of a spatial interference task, arrow and eye gaze generate opposite congruency effects, a classical congruency effect with arrows and a RCE with eye-gaze stimuli, when there is an explicit processing of the direction of stimuli. Second, the congruency effect with arrow stimuli and RCE with eye gaze stimuli disappeared in the implicit task, when the direction of stimuli was not relevant for the task. Finally, the congruency effect with the arrow and RCE with eye-gaze appeared in the explicit task even when the response was verbal, demonstrating that it is not necessary to generate a lateralized motor response to observe the above-mention effects.

Beyond the finding of a good explanation for the RCE with eye-gaze stimuli, data from the present research suggests that both eye-gaze and arrow direction significantly affect behaviour in a spatial interference paradigm only when they are task-relevant and explicitly processed. On the other hand, the fact that the RCE with eye-gaze stimuli was absent in the implicit task, both when the response was manual and when it was verbal, is not consistent with the eye-contact hypothesis (Cañadas & Lupiáñez, 2012; Marotta et al., 2018b, 2019a), since several studies have shown that eye-contact can be processed automatically and involuntarily (Mares et al., 2016; Sato et al., 2007; Stein et al., 2011; Xu et al., 2011). Furthermore, this finding is also relevant to dismiss any explanation based on response compatibility factors. Future research should keep investigating alternative plausible explanations as joint attention or joint distraction effects exclusively elicited by eye-gaze.

Declarations

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Conflicts of interest The authors declare no conflict of interest.

Data availability Readers seeking access to the data and experimental materials should contact the author Cristina Narganes-Pineda (cnarganes@ugr.es). Data and experimental materials are also available in the Open Science Framework repository (https://osf.io/aetg7/). No part of the study procedure or analyses were pre-registered prior to the research being conducted.

Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical guidelines laid down by the University of Granada, in accordance with the ethical standards of the 1964 Declaration of Helsinki (last update: Seoul, 2008) and was part of the research project (PSI2017-

84926-P) approved by the University of Granada Ethical Committee (536/CEIH/2018).

Informed consent Informed consent was obtained from all individual participants included in the study.

Chapter 7
Third Study

Neural basis of social attention: common and distinct mechanisms for social and non-social orienting stimuli

The content of this chapter is in preparation as:

Narganes-Pineda, C., Paz-Alonso, PM., Marotta, A., Lupiáñez, J. & Chica, A.B. Neural basis of social attention: common and distinct mechanisms for social and non-social orienting stimuli.

7.1 Abstract

Social and non-social directional stimuli trigger attentional processes, although research using gaze and arrow stimuli has indicated both similarities and differences in their effects. In a spatial interference paradigm, gaze and arrows have been shown to elicit opposite spatial congruency effects. This study extends these findings by evaluating the brain responses underlying these opposing effects. Results showed a common set of regions (right parieto-temporo-occipital) similarly involved in conflict resolution for arrow and gaze stimuli, which showed stronger co-activation for incongruent than congruent trials. The frontal eye field (FEF) showed stronger functional connectivity with occipital regions for congruent as compared to incongruent trials, and this effect was enhanced for gaze as compared to arrow stimuli in the right hemisphere. Moreover, spatial interference produced by incongruent (as compared to congruent) arrows was associated with increased functional coupling between the right FEF and a set of regions in the left hemisphere. This result was not observed for incongruent (as compared to congruent) gaze stimuli. These findings support the existence of shared and dissociable processing mechanisms for social and non-social orienting stimuli by revealing neural networks associated with spatial conflict resolution that are shared between gaze and arrow trials, as well as an additional set of regions that are differentially involved in the processing of each stimulus.

Keywords: Attentional Orienting, Social Attention, Social Cognition, Spatial Congruency Effect, Frontal Eye Field, Functional Connectivity.

7.2 Introduction

Social attention skills are notable in humans. Gaze, head, and body orientation help us determine other people's focus of attention and intentions. Accordingly, we tend to direct our attention towards the focus of other people's attention in order to infer their goals, intentions and actions (Nummenmaa & Calder, 2009). Humans are particularly adept at perceiving and discriminating gaze direction (George & Conty, 2008) , and gaze following is crucial for developing some cognitive processes, such as language, theory of mind, and emotion recognition. Neuroimaging and neuropsychological evidence have unravelled an extensive neural network (referred to as the "social brain") involved in social attention, including areas related to face and gaze perception, attention, emotion, and mental state attribution (Hadders-Algra, 2022; Itier & Batty, 2009; Nummenmaa & Calder, 2009). Although the neural network of the social brain extends over both hemispheres, right hemisphere activations are more pronounced (Freiwald et al., 2017).

Face perception and recognition involve the inferior occipital gyrus (IOG), the fusiform gyrus (FG), and the superior temporal sulcus (STS). These regions are associated with the visual analysis of different facial properties (Haxby et al., 2000; Nummenmaa et al., 2010), such as processing basic components, invariant facial aspects, and changeable facial aspects (Sato & Uono, 2019). The STS has been particularly implicated in gaze perception. While the anterior part of the STS (aSTS) seems to represent gaze direction with fine-grained accuracy (Carlin & Calder, 2013; Hadders-Algra, 2022), the posterior part of the STS (pSTS) has been mostly associated with the interpretation of the social intention of gaze, action observation, and theory of mind (Nummenmaa & Calder, 2009; Pfeiffer et al., 2013; Redcay et al., 2010; Yang et al., 2015). Apart from the perceptual processing of gaze, attention is usually attracted to the eyes and to the location the eyes are looking at. These attentional effects have been associated with the activation of parietal regions such as the superior intraparietal sulcus and the temporo-parietal junction (TPJ) (Lockhofen et al., 2014). Following the idea that humans show an automatic tendency to follow the gaze direction of others, some studies support the idea that the pSTS region and the dorsal attention system, superior parietal lobule (SPL), and frontal eye field (FEF) are implicated in goal-directed and exogenous shifts in attention (Nummenmaa & Calder, 2009). Specifically, the gaze direction effect in lateral and inferior parietal regions could reflect attentional orienting in response to gaze cues (Carlin & Calder, 2013).

Numerous studies have tested the assumption that orienting of attention by gaze direction, compared with other non-biological directional stimuli such as arrows, might be faster or more efficient, by comparing attentional orienting triggered eye-gaze with arrow stimuli using the spatial cueing paradigm (Birmingham & Kingstone, 2009; Capozzi & Ristic, 2018; Chica et al., 2014; Friesen & Kingstone, 1998; Galfano et al., 2012; Heyes, 2014). However, these studies found subtle or no behavioural differences between eye-gaze and arrow cues, leading some authors to propose that gaze attentional effects are at least partially driven by a domain-general attentional process (Chacón-Candia et al., 2022). At the neural level, when comparing attentional orienting to gaze and arrow cues, some studies have observed similar activations in fronto-parietal regions (Brignani et al., 2009; Callejas et al.,2014; Greene et al., 2009; Sato et al., 2009; Zhao et al., 2017). Other studies found subtle differences in cortical activations for social as compared to non-social cues (Caruana et al., 2015; Engell et al., 2010; Kingstone et al., 2004;

Lockhofen et al., 2014; Jelena Ristic & Giesbrecht, 2011; Tipper et al., 2008). Increased activation of ventral regions (TPJ and inferior parietal cortex) during attentional reorienting for invalid (spatially non-attended) gaze trials as compared to invalid arrow trials has been reported (Joseph et al., 2015), suggesting that gaze direction may automatically elicit expectations regarding other people's intentions and that TPJ is activated during invalid trials to redirect attention.

As reviewed above, behavioural effects observed in spatial cueing procedures with arrow and gaze cues are comparable, and the brain activations related to orienting attention triggered by these two stimuli are partially similar. However, other tasks have demonstrated qualitative behavioural differences when responding to arrow versus gaze stimuli (Chacón-Candia et al., 2020; Gregory & Jackson, 2017; Marotta et al., 2012, 2018). This observation has led some authors to propose that gaze triggers a domain-general orienting mechanism, like non-social cues, but also an additional social-specific mechanism (Klara Hemmerich et al., 2022). Perhaps the most appropriate experimental procedure for measuring this additional social mechanism is the spatial interference task used by Marotta et al. (2018), in which opposite behavioural effects for arrow and gaze stimuli were observed. In this paradigm, participants had to discriminate the direction of the targets (arrows or eye-gaze), which were randomly displayed to the left or right of a central fixation point. Consistent with a spatial interference effect (Lupiáñez & Funes, 2005), arrows elicited faster responses when their direction was congruent with their position (e.g., a left-pointing arrow presented to the left; classical spatial congruency effect) as compared to incongruent trials. However, eye-gaze stimuli produced faster reaction times (RTs) when they were incongruent (e.g., a left-looking eye-gaze stimulus presented to the right) as compared to congruent trials (the so-called Reversed Congruency Effect; RCE). In a follow-up electroencephalogram (EEG) study, Marotta et al. (2019) directly compared the temporal dynamics of the conflict processing triggered by eye-gaze and arrow stimuli in an electroencephalogram (EEG) study. They found similar effects on earlier event-related potential (ERP) components (P1 and N1) and a dissociation between eye-gaze and arrows only on late components (N2 and P3). The results were interpreted as suggesting that spatial conflict triggered by gaze and arrow stimuli is supported by both early shared and later dissociable processes.

The present study sought to investigate the neural mechanisms associated with attentional orienting elicited by social and non-social stimuli using the spatial interference paradigm. More specifically, we aimed at investigating the congruency and reversed congruency effects produced by arrows and gaze stimuli, respectively. We used functional Magnetic Resonance Imaging (fMRI) while participants performed a spatial interference task. Behaviourally, we expected opposite effects for arrow and gaze stimuli, in line with previous studies (Cañadas & Lupiáñez, 2012; Hemmerich et al., 2022; Jones, 2015; Marotta et al., 2018). On the neural level, our two main hypotheses were that: (1) brain regions associated with conflict resolution within the frontal and the parietal cortex would show similar congruency neural effects for arrows and gaze stimuli (for incongruent as compared to congruent stimuli) (Callejas et al.,2014; Liu et al., 2004); and (2) more ventral regions, such as the STS and right TPJ, as well as other face-selective regions (IOG and FG), might show a functional pattern related to the behavioural RCE for congruent as compared to incongruent gaze stimuli.

Methods

Participants

A total sample of 33 right-handed volunteers (mean age= 22.5 years, SD= 3.17 years, 7 males) from the University of Granada took part in the study. Participants reported normal or corrected-to-normal vision, normal colour perception and no neurological or psychiatric disorders. They followed all the safety requirements to undergo MRI scanning. Participants signed an informed consent form prior to their participation in the study and were informed about their right to withdraw from the experiment at any time. All participants received monetary compensation for their time and effort (10 €/h) and were naïve about the purpose of the experiment. This experiment is part of a larger research project, which has been positively evaluated by the University of Granada Ethical Committee (536/CEIH/2018), in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

The sample size was calculated based on the results of a previous study in which, using a similar paradigm, the two-way interaction (Target Type x Congruency; see Methods and Results) presented a size effect of η^2p = 0.60 (see Experiment 1 – Explicit Task, Narganes-Pineda et al., 2022). The *WebPower* R package (Zhang et al., 2018) was used, and a sample of at least 13 participants was required for a repeated-measures ANOVA, F-tests, with an alpha of .05 and a power of .95. We decided to run a larger sample of 33 participants to obtain stronger statistical power for the fMRI analyses.

Data from 3 participants were excluded from further analyses due to either excessive head motion during scanning (2 participants; see *fMRI Data Analysis* section below) or withdrawal from the study (1 participant). Thus, the final sample used in the behavioural and fMRI analyses was 30 participants (mean age= 22.5 years, SD= 3.28 years, 6 males).

Apparatus and Stimuli

Stimuli presentation, timing, and data collection were controlled using E-Prime 2.0 (Schneider et al., 2002). Stimuli were displayed on a screen (NNL, 32′′, 1024 × 768, 60 Hz) located at the back of the scanner (located at 2.12 m), reflected onto a head coil-mounted mirror inside the scanner. Behavioural responses were recorded with two MRI compatible response devices, one in each hand, connected by optical fiber to an Evoke Response Pad interface box (Resonance Technology INC., http://www.mrivideo.com/). All stimuli were presented on a grey background. In each trial, a black fixation point (0.5 x 0.5º) was presented at the center of the screen. The target stimuli consisted of 0.5 x 2.5º images of two arrows, two rectangles, and two full open or closed eyes, presented to either the left or right of the fixation point (see Figure 1). The distance from the fixation point to the center of the lateral stimulus was 7 cm. The eyes were cropped from the original faces of the NimStim Set of Facial Expressions (https://danlab.psychology.columbia.edu/content/nimstim-set-facial-expressions) using Adobe Photoshop CS.

Procedure

The experiment consisted of 5 functional runs. Each functional run lasted for approximately 8.65 minutes. There were a total of 960 trials, 192 per run, which included all experimental conditions. The duration of the jitter fixation and the order of trial types were determined with an optimal sequencing programme designed to maximize the efficiency of recovery of the Blood-Oxygen-Level Dependent (BOLD) response (Optseq II; https://surfer.nmr.mgh.harvard.edu/optseq/). The jitter fixation periods (with a duration varying randomly between 500-9000 ms; 35% of trials) were interleaved with the experimental trials as determined by the optimization programme. Before acquiring functional data, participants received instructions and performed a practice block of 27 trials. Visual feedback was provided during practice trials when no response or incorrect responses were detected.

The trial sequence is represented in Figure 1. Each trial started with a fixation point lasting for 500 ms. Participants were instructed to keep their eyes on the fixation point throughout the experiment. The target was then presented at the left or the right location (two arrows, two open eyes, two rectangles, or two closed eyes), for 1500 ms, with directional targets pointing/looking towards the right or the left location. All targets were randomly presented on a trial-by-trial basis, so that either open or closed eyes or pairs of arrows or rectangles could appear on each trial. Participants were instructed to respond to the direction (left or right) that the arrows were pointing at or that the eyes were looking at, by pressing the left key with the left index finger for arrows/eyes pointing to the left, and the right key with the right index finger for arrows/eyes pointing to the right, regardless of the target location. When a neutral stimulus appeared (rectangles or closed eyes, which do not indicate any direction), participants were required to press a different key with either their right or left thumb, counterbalanced between participants. Participants were instructed to respond as fast and accurately as possible within 1500 ms from stimulus onset.

According to the experimental design, trials were *congruent*, if the target pointed or looked in the same direction as its location on the screen (i.e., a target pointing to the right that was presented on the right side of the screen); *incongruent*, if the target pointed in the opposite direction to its location (i.e., a target pointing to the right that was presented on the left side of the screen); or *neutral,* when closed eyes or rectangles were presented.

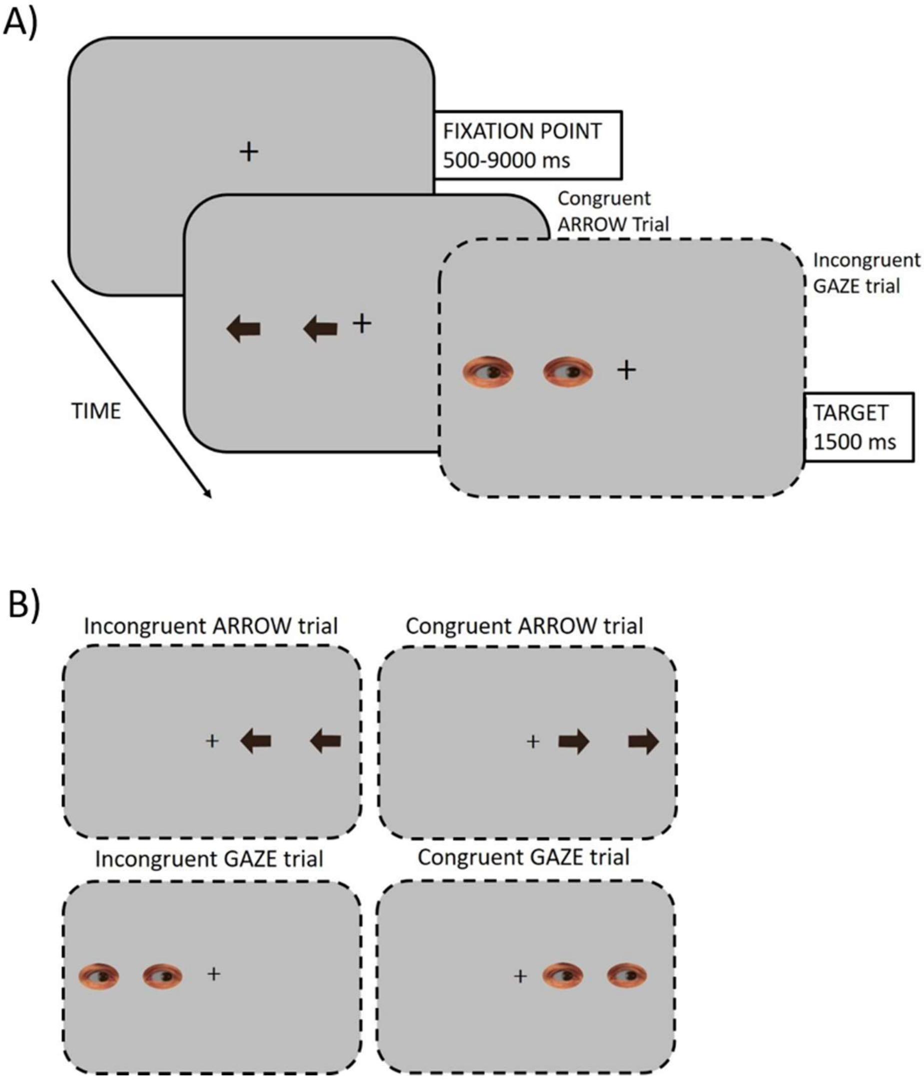


Figure 1. A) Schematic representation of the trial sequence. In the example, a congruent arrow trial is represented, together with an incongruent gaze trial. B) Representation of congruent and incongruent gaze and arrow stimuli.

fMRI Data Acquisition

Functional and structural images were collected on a 3-T Siemens PRISMA Fit whole-body MRI scanner at the Mind, Brain, and Behaviour Research Center (CIMCYC, University of Granada), using a 64-channel whole-head coil. Participants wore earplugs to reduce scanner noise. To limit head movement, foam padding was added between the coil and the participants' heads. In addition, participants were asked to remain as still as possible.

Functional (T2*-weighted) multiband images were acquired using the following acquisition parameters: multiband factor = 4, time-to-repetition (TR) = 1000 ms, time-to-echo (TE) = 34.80 ms, 56 interleaved 3-mm cubic axial slides, no inter-slice gap, flip angle = 56°, field of view (FoV) = 228 mm, 525 volumes per run. Prior to each functional scan, six volumes were discarded to allow for T1-equilibration effects. High-resolution T1-weighted anatomical images were also collected with the following acquisition parameters: TR = 2530 ms, TE = 2.36 ms, flip angle = 7°, slice thickness = 1 mm, FoV = 256 mm, 176 slices.

fMRI Data Analysis

Standard preprocessing routines and analyses were conducted using SPM12 (Wellcome Centre for Human Neuroimaging, London). Images were corrected for differences in slice acquisition timing and realigned to the first volume by means of rigid-body transformation. Then a partial spatial smoothing of functional images was performed using a 4 mm full width at half max (FWHM) isotropic Gaussian kernel. After partial smoothing, the motion parameters extracted from the realignment step were used for additional motion correction algorithms implemented by the ArtRepair toolbox (Stanford Psychiatric Neuroimaging

Laboratory). With this method, we were able to repair outlier volumes with sudden scan-to-scan motion exceeding 0.5 mm and/or 1.3 % variation in global intensity by linear interpolation between the nearest non-outlier time points (Mazaika et al., 2009). Participants with more than 10 % to-be-corrected outlier volumes across functional runs were excluded (i.e., 1 participant). Within each functional run, we also examined drift motion over 3 mm/degrees in translation (x, y, z) or rotation (yaw, pitch, roll) directions, excluding 1 participant who showed drift motion above this threshold. After volume repair, structural and functional volumes were coregistered and spatially normalized to T1 and echo-planar imaging templates, respectively. The normalization algorithm used a 12-parameter affine transformation together with a nonlinear transformation involving cosine basis functions. During normalization, the volumes were sampled to 3-mm cubic voxels. Templates were based on the MNI305 stereotaxic space (Cocosco et al., 1997). Next, functional volumes were spatially smoothed with a 7mm FWHM isotropic Gaussian kernel. Due to the quadratic relation between separate smoothing operations, the total smoothing applied to the functional data was approximately equivalent to smoothing with an 8-mm FWHM Gaussian kernel. Finally, time series were temporally filtered to eliminate contamination from slow frequency drift (high-pass filter with a cut-off period of 128 s).

Statistical analyses were performed on individual participants' data applying the general linear model (GLM). The fMRI time series data were modelled by a series of events convolved with a canonical hemodynamic response function (HRF). Six fMRI experimental conditions (i.e., arrow congruent, arrow incongruent, arrow neutral, gaze congruent, gaze incongruent, gaze neutral) were modelled as 2s events, with each trial time-locked to the initial presentation of each stimulus. Neutral trials were initially added to the procedure for use as a baseline condition. However, comparisons of arrows>neutral and gaze>neutral demonstrated that the BOLD signal in occipito-temporal regions was increased for neutral as compared to either arrows or gaze conditions. This might be due to the fact that neutral trials were less likely to be presented than congruent and incongruent trials. Therefore, we decided to exclude neutral trials from the analyses. Anticipatory responses, trials with no responses, and trials with the incorrect key pressed were considered errors and were modelled separately and not considered in the main analysis. The produced functions were entered as covariates of interest in the GLM, together with the motion parameters for translation (x, y, and z) and rotation (yaw, pitch, and roll), which were entered as covariates of no interest. SPM12 FAST was used for temporal autocorrelation modelling in this GLM due to its optimal performance in terms of removing residual autocorrelated noise in first-level analyses (Olszowy et al., 2019). The least-squares parameter estimates of the height of the best-fitting canonical HRF for each condition were used in pairwise contrasts. Contrast images, computed on a participant-by-participant basis were submitted to group analysis. At the group level, whole-brain contrasts between conditions were computed by performing one-sample t-tests on these images, treating participants as a random effect, and using a family-wise error (FWE) correction at the cluster level with a voxel-extent threshold of $p < .001$. All coordinates along the article are reported in Montreal Neurological Institute (MNI) atlas space.

Regions-of-Interest (ROI) analyses were conducted with the MARSBAR toolbox of SPM12 (Brett et al., 2002). ROIs consisted of significantly active voxels identified from the All Stimuli > Null whole-brain functional contrast (cluster-wise FWE corrected, voxel-extent threshold of $p < .001$) across all participants within specific

MARSBAR anatomical ROIs. A set of ROIs (the centre of mass and the volume in mm^3 are indicated between parentheses) previously related to attentional and gaze processing were built for ROI and functional connectivity analyses. These ROIs included bilateral FEF (left: -22.3, -2.78, 66; 3584 mm^3, right: 28.8, -4.88, 62.8; 2280 mm^3), bilateral FG (left: -33.5, -59.5, -16.4; 9056 mm^3, right: 34.4, -59.3,-16; 7292 mm^3), bilateral IOG (left: -37.4, -76.8, -8.83; 5400 mm^3, right: 38.4, -78, -9.45; 4144 mm^3), bilateral inferior parietal lobe (IPL; left: -41, -41.7, 46.1; 11088 mm^3, right: 38.4, -44.6, 49.6; 3736 mm^3), bilateral SPL (left: -24.6, -56.6, 58.8; 9760 mm^3, right: 26.6, -56.4, 60; 8008 mm^3), right angular gyrus (31.3, -59.1, 44.5; 1272 mm^3), right supramarginal gyrus (42.2, -35.9, 42.3; 920 mm^3), right middle and inferior temporal gyrus (MTG/ITG; 48.9, -59.9, -2.72.6; 10640 mm^3). In the All Stimuli > Null comparison the right STS did not show activation. However, given this comparison is an average of arrows and gaze, it is possible that this region was not activated because it is more activated for gaze than arrows. As this region is particularly important for gaze processing, we nevertheless added it to the analyses based on previous literature (50, -47, 13; 312 mm^3; Schobert et al., 2018). For each ROI, we conducted a repeated-measures analysis of variance (ANOVA) on the parameter estimates values, with Target type and Congruency as factors. Outlier values outside the upper (75% + 1.5 IQR) or lower (25% - 1.5 IQR) quartiles in each condition were removed from the analysis (Goss-Sampson, 2022).

Finally, we examined functional connectivity via the beta-series correlation method (Rissman et al., 2004) implemented in SPM12 with custom MATLAB scripts. The canonical HRF in SPM was fit to each trial from each experimental condition, and the resulting parameter estimates (i.e., beta values) were sorted according to the study conditions of interest (arrow congruent, arrow incongruent, gaze congruent, gaze incongruent) to produce a condition-specific beta series for each voxel. Two different functional connectivity analyses were performed: 1) intra-hemisphere pairwise functional connectivity, and 2) whole-brain functional connectivity using right FEF as the seed region (see Results section).

For pairwise functional connectivity analyses, we first calculated beta-series correlation values for each ROI at the participant level. Next, we examined interactions in pairwise functional connectivity between pairs of ROIs within the same hemisphere. We decided not to explore coactivation between hemispheres to reduce the number of comparisons. Because correlation coefficients are inherently restricted to the range from − 1 to + 1, an arc-hyperbolic tangent transform was applied to these beta-series correlation r-values to make the null hypothesis sampling distribution approach that of the normal distribution (Fisher, 1922). These Fisher's z normally distributed values were then submitted to repeated-measures ANOVAs with the factors Target type and Congruency. Outlier values outside the upper (75% + 1.5 IQR) or lower (25% - 1.5 IQR) quartiles in each condition were removed from the analysis (Goss-Sampson, 2022).

For the whole-brain functional connectivity analysis, the beta series associated with the right FEF as a seed were correlated with voxels across the entire brain to produce beta-correlation images. Contrasts between beta-correlation images were also subjected to an arc-hyperbolic tangent transform to allow for statistical inference based on temporally coupled fluctuations with this region. Incongruent > Congruent t-tests were separately performed for arrows and gaze stimuli on the resulting subject contrast images to produce group correlation contrast maps with a voxel threshold extent of $p < .001$, cluster-wise FWE corrected.

Data are available in the Open Science Framework repository (https://osf.io/y8qsu/?view_only=9b7832d63a554990bd927b817c33bc71) .

RESULTS

Behavioural Results

Following Marotta et al. (2018), trials with incorrect responses (3.27%), anticipatory responses (0.21%), and correct response trials with RTs faster than 200 ms (0.88%) or slower than 1300 ms (0.53%) were excluded from RT analysis.

Mean RTs and percentages of errors for each experimental condition are shown in Table 1. Mean RT data were submitted to 2 (Target Type: eyes and arrow) × 2 (Congruency: congruent and incongruent) repeated measures ANOVA.

Table 1. Mean correct RTs (in ms) and percentage of incorrect responses (IR) (with their corresponding standard deviations, -SD-) for each experimental condition.

	Gaze				**Arrow**			
	RT	**SD**	**%IR**	**SD**	**RT**	**SD**	**%IR**	**SD**
Congruent	679	77	2.51	2.26	586	64	0.80	0.95
Incongruent	674	75	3.42	3.03	612	70	1.45	1.62

The analysis of the mean RTs revealed a main effect of Target Type, F(1,29)= 230.74, MSE= 784, p<0.001, η^2p = 0.89, with shorter RTs for arrow (599 ms) than for gaze targets (676 ms). The main effect of Congruency was also significant, F(1,29)= 6.74, MSE= 553, $p<0.015$, η^2p = 0.19, with shorter RTs for congruent (633 ms) than for incongruent trials (642 ms). The crucial Target Type x Congruency interaction was significant, F(1,29)= 30.12, MSE= 236, $p<0.001$, η^2p = 0.51. Planned comparisons showed that for arrow stimuli, RTs were significantly slower for incongruent (612 ms) than for congruent trials (586 ms), F(1,29)= 47.53, MSE=222 , $p<0.001$, η^2p =0.62. In contrast, for gaze stimuli, although not significantly, the expected reversed tendency was observed with slower responses for congruent (679 ms) than incongruent (674 ms) trials, F<1 (Figure 2).

The analysis of errors showed a main effect of Target Type, F(1,29)=23.01, $p<0.001$ η^2p=0.44, with more errors for gaze targets (2.96%) than arrow targets (1.13%). The main effect of Congruency was also significant, F(1,29)=12.58, p=0.001 η^2p=0.30, with more errors for incongruent (1.65%) than congruent trials (2.44%). The interaction Target type x Congruency was not significant, F<1.

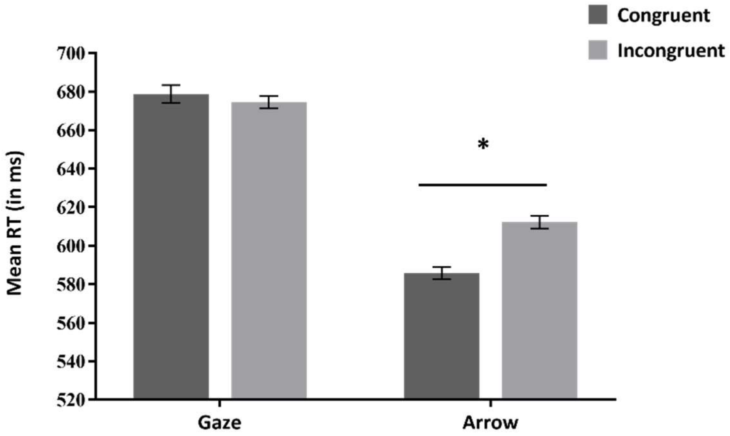


Figure 2. Mean RT for each Target Type and Congruency conditions. Cousineau's method, (2005) was used to calculate the standard error of the mean represented as error bars. Asterisks denote statistically significant planned comparisons ($p<0.001$).

fMRI Results

The main aim of the fMRI analysis was to examine the hypotheses that there are common mechanisms for the congruency effect produced by arrows and gaze reflected in increased neural activations and/or co-activations for incongruent than congruent trials, and additional mechanisms associated with the RCE produced by gaze resulting in increased neural activations and/or co-activations for congruent than incongruent trials. In addition, gaze is expected to increase brain responses in the FG, the STS, the IOG, and TPJ compared to arrow (especially in the right hemisphere).

First, we report the results of the ROI analyses, then the pairwise FC analyses, and finally the whole-brain FC analyses.

ROIs Analysis

The whole-brain contrast All Stimuli > Null revealed the regions that demonstrated larger BOLD responses when both gaze and arrow stimuli, in congruent and incongruent conditions, were presented compared to fixation. In line with previous evidence we selected the regions of interest (see *Methods* section) related to gaze processing, attentional processing, and cognitive control. In these regions, we found an increase in the BOLD signal for all the variables in our design with respect to the Null baseline in bilateral FEF, bilateral SPL and IPL, bilateral FG, and bilateral IOG. Further regions that showed increased activation in the right hemisphere only in respect to baseline were the angular gyrus, supramarginal gyrus, pSTS, and ITG/MTG (Figure 3).

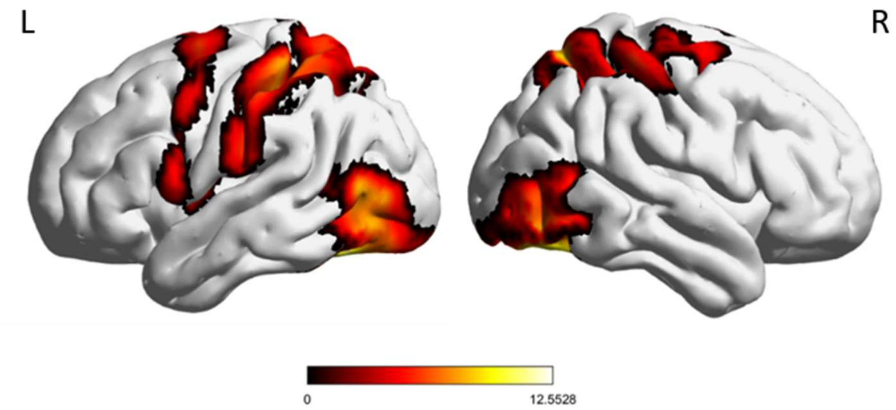


Figure 3. Brain renderings showing activations for All Stimuli > Null whole-brain contrast (cluster-wise FWE corrected with a voxel-extent threshold of $p < .001$). The colour bar denotes t-values. L: Left hemisphere. R: Right hemisphere.

The 2 (Target Type: arrows vs. gaze) x 2 (Congruency: congruent vs. incongruent) ANOVA on the ROI parameter estimates revealed a group of regions with significant main effects of Target Type and Congruency (see Table 2). All regions presented an increased % signal change for gaze compared with arrow trials, except the left IPL. Another set of regions in the left hemisphere, including the FEF, IPL, SPL, FG, and IOG, revealed a significant main effect of Congruency, with larger BOLD signal intensity for incongruent than congruent trials. In the right hemisphere, only the STS showed a main effect of Congruency, with larger % signal change for incongruent than congruent trials. The interaction Target Type by Congruency was not significant in any of the examined ROIs ($ps \geq 0.052$).

Table 2. ROIs showing significant main effects of Target Type and Congruency in the parameter estimate analysis.

Brain Area	**F**	**MSE**	**p**	**η^2_p**
Main effect of Target Type				
L FEF	22.05	0.09	<0.001	0.45
R FEF	16.55	0.12	<0.001	0.40
L SPL	8.33	0.20	0.008	0.24
R SPL	8.60	0.27	0.007	0.25
R IPL	16.82	0.20	<0.001	0.37
L FG	68.06	0.30	<0.001	0.72
R FG	106.43	0.17	<0.001	0.80
L IOG	76.82	0.22	<0.001	0.74
R IOG	149.75	0.23	<0.001	0.85
R Angular	7.13	0.20	0.013	0.21
R Supramarginal	19.25	0.12	<0.001	0.42
R MTG/ITG	24.54	0.12	<0.001	0.46
R pSTS	13.78	0.09	<0.001	0.35
Main effect of Congruency				
L FEF	11.44	0.08	0.002	0.30
L SPL	6.81	0.14	0.015	0.21
L IPL	4.67	0.12	0.041	0.16
L FG	8.07	0.12	0.009	0.24
L IOG	13.05	0.12	0.001	0.33
R pSTS	5.62	0.05	0.025	0.18

FEF, frontal eye field; FG, fusiform gyrus; IOG, inferior occipital gyrus; IPL, inferior parietal lobe; L, left; MTG/ITG, middle temporal gyrus/inferior temporal gyrus; pSTS, posterior superior temporal sulcus; R, right; SPL, superior parietal lobe.

Pairwise Functional Connectivity Analysis

The pairwise functional connectivity analysis (2x2 ANOVA for each pair of regions of interest) revealed a main effect of congruency in the functional coupling between the left hemisphere FEF and the IOG. These regions were more strongly coupled for congruent trials compared to incongruent trials ($F(1, 28) = 8.037$, $p = .008$, $\eta^2_p = .223$). In the right hemisphere, two pairs of regions demonstrated a main effect of congruency, with a larger co-activation for incongruent than congruent trials: Angular gyrus with IOG ($F(1, 29) = 5.722$, $p = .023$, $\eta^2_p = .165$) and supramarginal gyrus with ITG/MTG ($F(1, 27) = 4.437$, $p = .045$, $\eta^2_p = .141$) (Figure 4, panel A). A further two pairs of regions in the right hemisphere (FEF-FG and FEF-IOG) demonstrated a main effect of congruency, that was, however, better explained by the interaction between Target Type x Congruency (FEF-FG, $F(1, 28) = 4.810$, $p = .037$, $\eta^2_p = .147$; and FEF-IOG, $F(1, 27) = 4.394$, $p = .046$, $\eta^2_p = .140$). These pairs of regions showed greater co-activations for congruent trials compared with incongruent trials for gaze stimuli (both comparisons $p<.001$), whereas coupling between congruent and incongruent trials was comparable for arrow stimuli (both comparisons $F<1$). The right FEF and right IPL also showed a significant Target Type by Congruency interaction, $F(1, 29) = 4.799$, $p = .037$, $\eta^2_p = .142$, but planned comparisons revealed no significant differences between congruent and incongruent trials either for gaze ($p=.087$) or for arrows ($p=.207$) (Figure 4, panel B).

We speculated that these results might be affected by the location of the stimuli. To explore this issue, we reanalysed the data considering stimulus location as a factor. Results demonstrated that location did not modulate the Target Location x Target Type x Congruency interaction for any of the ROIs examined (all ps>.05), except for the right supramarginal-SPL pair of ROIs Target Location x Target Type x Congruency interaction, F(1,27)=4.262, p =.049, η^2_p = .136). However, this interaction is difficult to understand, as planned comparisons comparing congruent and incongruent trials for gaze and arrows in each stimulus location were not significant (all ps>.236). Therefore, we could conclude that the location of the stimulus did not affect the reported results.

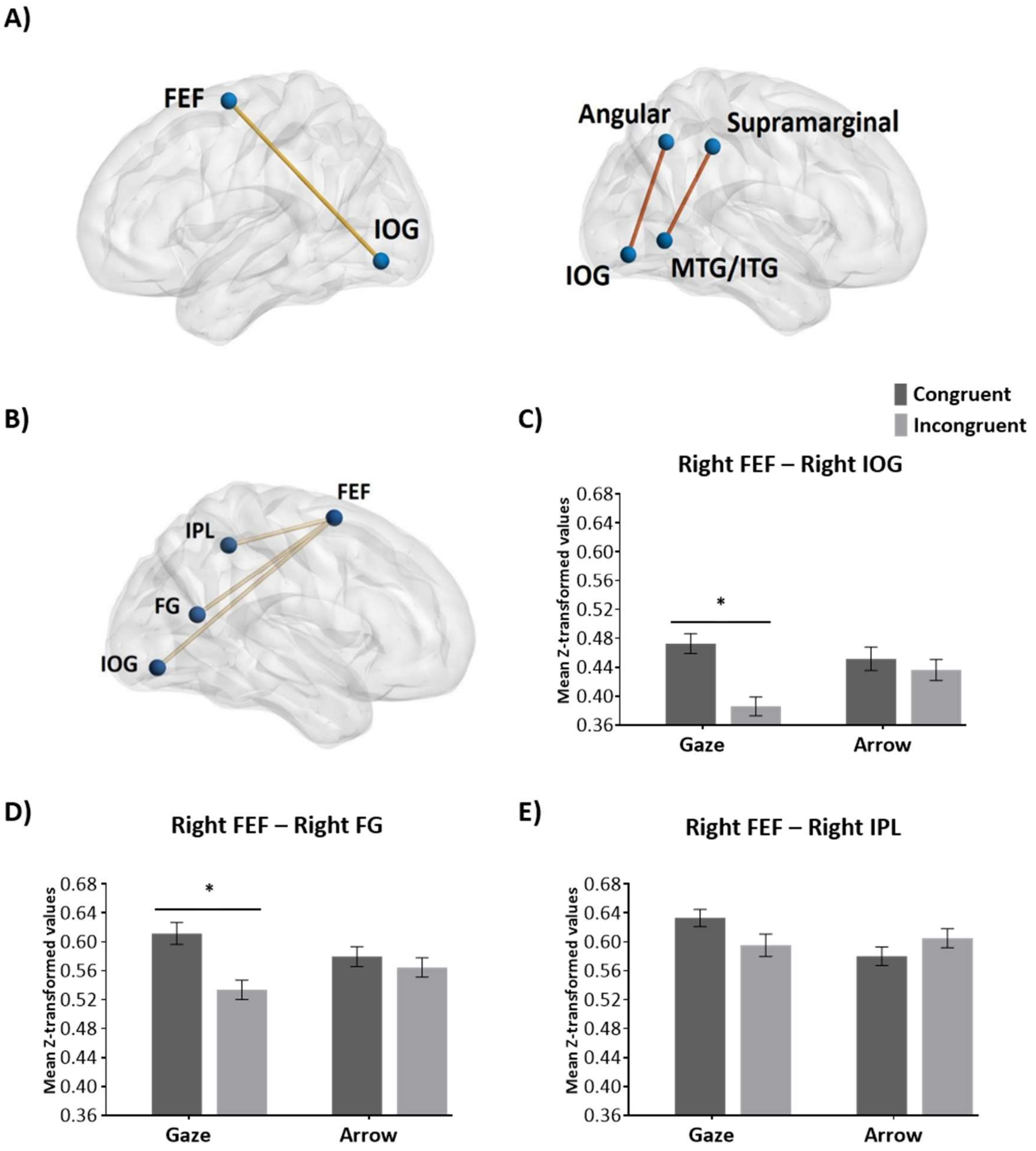


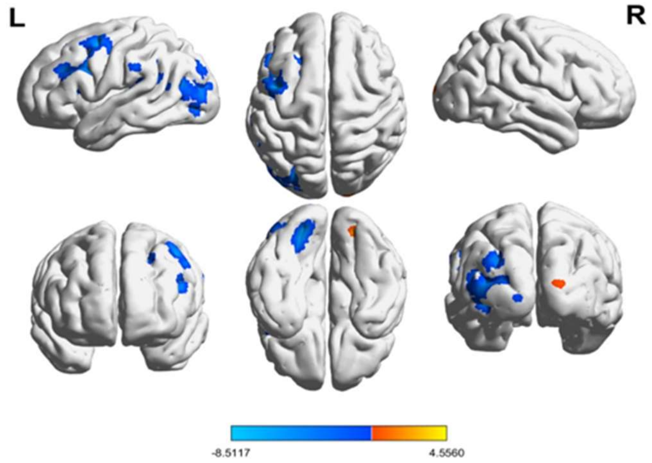
Figure 4. A) Representation of the pairs of regions showing a main effect of Congruency (and no Congruency x Target type interaction) in pairwise functional connectivity analysis. Yellow edges indicate congruent trials > incongruent trials. Orange edges indicate incongruent trials > congruent trials. L: Left hemisphere. R: Right hemisphere. B) Graphical representation of the 3 pairs of regions demonstrating a significant interaction between Target type and Congruency in pairwise functional connectivity analyses. Edges indicate that the interaction was significant in the analysis of these three pairs of regions. C-D-E) Fisher's Z values for the Target type by Congruency interaction in the functional

coactivation between the FEF-IOG, FEF-FG, and FEF-IPL in the right hemisphere. Cousineau's method (2005) was used to calculate the standard errors of the means represented as error bars. Asterisks represent statistically significant planned comparisons ($p<0.05$).

Whole-brain Functional Connectivity Analysis

Finally, whole-brain functional connectivity analysis was performed using a seed placed in the right FEF, which demonstrated the crucial Target Type x Congruency interaction in the pairwise functional connectivity analysis with occipital, temporal, and parietal regions. This analysis was performed to ensure we had not missed potentially relevant co-activations between the right FEF and the rest of the brain in the previous ROI-based pairwise connectivity analysis. In this analysis, we compared the whole-brain connectivity of the right FEF on congruent vs. incongruent trials, separately for arrow stimuli and gaze stimuli. The results of these comparisons are shown in Figure 5.

A) Arrow, Congruent > Incongruent



B) Gaze, Congruent > Incongruent

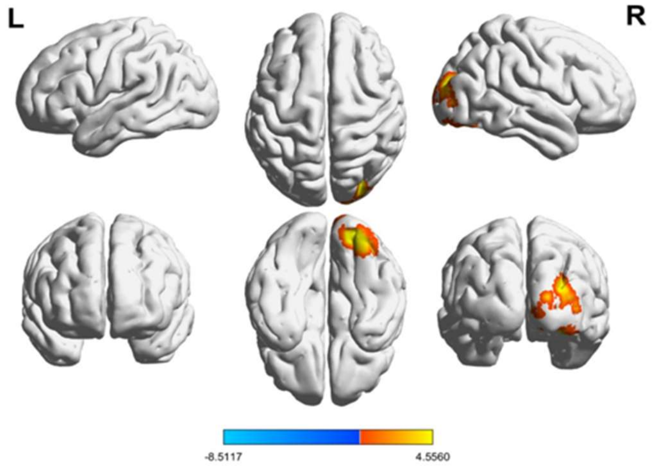


Figure 5. Whole-brain functional connectivity analysis using the right FEF as a seed for arrows (A) and gaze (B) for the contrast congruent > incongruent ($p < 0.001$, voxel-wise FWE corrected). The colour bar denotes t-values. L: Left hemisphere. R: Right hemisphere.

7.3 Discussion

The ability of gaze following is acquired in early childhood (Hood et al., 1998; Vaidya et al., 2011) and is crucial for fruitful social interactions. When the gaze is used as a cue, responses are facilitated if stimuli are presented at the location that the gaze is directed at (Brignani et al., 2009; Friesen et al., 2004; Shepherd, 2010). Similar behavioural results have been observed with non-social stimuli that are often presented in our environment, such as arrows. Arrows orient attention to the location they are pointing at, even if they are not predictive of where targets will appear (Actis-Grosso & Ricciardelli, 2017; Galfano et al., 2012; Heyes, 2014; Hommel et al., 2001; Santiesteban et al., 2014). Despite predictions that attentional orienting to gaze should be larger or more automatic than attentional orienting to arrows (Friesen & Kingstone, 1998; Hayward & Ristic, 2013), comparable behavioural effects (Chacón-Candia et al., 2022) and highly similar brain responses (Callejas et al.,2014; Sato et al., 2009; Tipper et al., 2008; Zhao et al., 2017) have been observed when gaze and arrows have been used as cues.

However, opposite behavioural effects have been observed when gaze and arrows have been used as targets in the spatial interference paradigm, (Cañadas & Lupiáñez, 2012; Jones, 2015; Marotta et al., 2018, 2019; Narganes-Pineda et al., 2022; Torres-Marín et al., 2017). When an arrow is presented on the right, point right (congruent trial), responses are faster and/or more accurate than if the arrow is presented on the left, pointing right (incongruent trial) (Lupiáñez & Funes, 2005). Slower responding on incongruent trials reflects the conflict created by stimuli that activate two different spatial codes, the spatial location where the stimulus is presented (irrelevant to the task) and the location the arrow points to (relevant to the task) (C. Luo & Proctor, 2013). Interestingly, when eyes are presented as targets, opposite congruency effects have been observed, i.e., responses are slower and/or less accurate for congruent than incongruent trials (Marotta et al., 2018, 2019). Several hypotheses have been proposed to explain this RCE with gaze (Hemmerich et al., 2022; Marotta et al., 2018, 2019), although the underlying cognitive and neural mechanisms remain unknown.

In this study, we examined the neural mechanisms associated with spatial conflict elicited by arrows and gaze stimuli using the spatial interference paradigm in an fMRI setting. At the behavioural level, gaze produced slower responses as compared to arrows, as expected based on previous research (Vlamings et al., 2005). This has been suggested to result from gaze producing an overall larger attentional capture due to social meaning and perceptual complexity (Hietanen et al., 2006; Marotta et al., 2018). More importantly our behavioural results demonstrated the expected interaction between Congruency and Target type. For arrows, responses were faster for congruent than incongruent trials, demonstrating the congruency effect. In contrast, no significant differences were observed for gaze between congruent and incongruent trials. Although the RCE was not observed, this might be due to the adaptation of the procedure for the fMRI design.

Previous research has shown that the RCE for gaze is only present when the previous trial is incongruent (Klara Hemmerich et al., 2022), which is in line with the assumption that the RCE effect produced by gaze is the result of a standard congruency effect (i.e., the same produced by arrows) and an opposite effect specific to gaze (Marotta et al., 2019). This means that the RCE is only observed when the standard congruency effect is reduced by a prior incongruence (Blais et al., 2014; Klara Hemmerich et al., 2022). For this reason, we decided to reanalyse our behavioural data, including only those trials that were preceded by incongruent trials. This modification led to a clearly significant RCE for gaze (RCE: F(2,58)= 37.873, p<.001, η^2p =0.57). Therefore, although the RCE for gaze was not observed overall, we are confident that the paradigm performed as expected, as the congruency effect was significantly different for gaze and arrow stimuli (significant interaction between Congruency and Target type), and the RCE was observed after incongruent trials, when the standard congruency effect was reduced.

At the neural level, imaging results showed an overall increase in BOLD responses for gaze versus arrow stimuli in a distributed set of fronto-parietal-temporal-occipital areas. The strong bilateral activation of FG and IOG found in the parameter estimate ROI analysis may reflect increased processing of social gaze stimuli. Indeed, in addition to their implication in facial processing (Haxby et al., 2000), the contribution of the FG and IOG to gaze perception has also been shown (Ethofer et al., 2011; Nummenmaa et al., 2010). Furthermore, our results are consistent with studies reporting that FG is more responsive to social than non-social stimuli (Kanwisher et al., 1997; Kanwisher, 2000; Tong et al., 2000). We also showed increased pSTS activation for the gaze > arrow contrast in the parameter estimate ROI analysis. This result is in line with previous results (Hooker et al., 2003; Kingstone et al., 2004) and is consistent with the view that STS is not only involved in gaze direction processing but also more generally in the processing of biologically significant stimuli (Carlin & Calder, 2013; Hooker et al., 2003; Materna et al., 2008; Yang et al., 2015).

One of the main questions that motivated our research was to explore if shared or dissociable processes support the spatial conflict triggered by gaze and arrow stimuli. We hypothesized that some brain regions associated with conflict resolution within the frontal and the parietal cortex would show similar congruency effects for arrows and gaze stimuli, while more ventral regions such as the STS and right TPJ, as well as other face-selective regions (IOG and FG), might show a pattern related to the behavioural RCE. Our results confirmed that the processing of conflict resolution produced by gaze and arrow stimuli is supported by both shared and dissociable mechanisms. A set of regions in the left hemisphere, including the FEF, IPL, SPL, FG and IOG, demonstrated larger BOLD responses for the incongruent condition relative to the congruent condition. The pSTS in the right hemisphere also demonstrated larger BOLD responses for the incongruent than the congruent condition. These results agree with previous studies (Braver et al., 2021; Greene et al., 2009; J. K. Hietanen et al., 2006; Liu et al., 2004; Sato et al., 2009), showing no differences in the overall BOLD activation for congruent and incongruent arrows and gaze stimuli. For both stimuli, incongruent as compared to congruent trials led to stronger coupling of regions within the ventral attentional network (the right angular and the right supramarginal gyrus) with ipsilateral temporo-occipital regions (i.e., IOG, MTG/ITG). The ventral network has been reliably related to conflict detection and attentional re-orienting (Corbetta & Shulman, 2002; Joseph et al., 2015; Kincade et al., 2005), two mechanisms involved in responding to incongruent trials in the present paradigm. As this is a shared mechanism between the processing of incongruent arrows and gaze stimuli, it demonstrates that even though responses were not slower for incongruent than congruent gaze stimuli, the former caused some conflict in the brain, which was resolved through the functional coupling of these regions. These findings complement functional neuroimaging evidence showing a similar activation of the ventrolateral attention control network when gaze or other behaviourally relevant stimuli, such as arrows, are used to orient attention (Callejas et al.,2014; Corbetta et al., 2008; Sato et al., 2009). As such, this evidence implies the existence of domain-general attentional processes that respond to the directionality of the stimulus regardless of whether the stimulus is social or non-social.

The FEF was more strongly coactivated with the IOG for congruent than incongruent trials. This effect is comparable for arrows and gaze in the left hemisphere, although an interaction with Target Type was observed in the right hemisphere. The functional coupling between the right FEF-IOG and right FEF-FG was stronger for congruent than incongruent trials for gaze stimuli but not for arrows. This is consistent with the RCE previously observed with gaze (Marotta et al., 2018, 2019). This result was confirmed by a whole-brain functional connectivity analysis in which the seed was placed in the right FEF. For gaze stimuli, the right FEF was more strongly connected with the ipsilateral occipital cortex for congruent than incongruent trials. In contrast, for arrow stimuli, the right FEF was more strongly coupled with a distributed set of regions of the contralateral hemisphere for incongruent than congruent trials, an effect that was not at all observed for incongruent gaze stimuli. These opposing effects indicate a dissociable mechanism between arrows and gaze processing.

The FEF is part of the dorsal attentional network proposed by Corbetta and colleagues (2008, 2002), whose activation has been associated with generating and maintaining endogenous signals based on current goals (Bressler et al., 2008; Vossel et al., 2014). The dorsal network sends top-down signals that bias the processing of relevant stimulus features and locations in the sensory cortex. The FEF also activates during reorienting, with enhanced responses when targets appear at unexpected locations (Kelley et al., 2008; Torriero et al., 2019). In our data, the coactivation of the FEF with occipital regions is larger for congruent trials (e.g., when the target appears on the right, pointing right, and therefore only one side of space is relevant), than for incongruent trials (e.g., when the target appears on the right, pointing left, and therefore the two sides of space are relevant), and this effect in larger for gaze than arrow stimuli in the right hemisphere. According to Corbetta's model, the FEF biases the processing of goal-relevant stimuli and locations in the visual cortex. Although this is a common process for arrow and gaze in the left hemisphere, in the right hemisphere this process is enhanced for gaze as compared to arrows, consistent with the RCE usually observed for gaze. This result seems consistent with the "joint-distraction" explanation of the RCE produced by gaze (Klara Hemmerich et al., 2022).

The “joint-distraction” account of the RCE proposes that congruent gaze stimuli (e.g., eyes presented on the right, looking right) direct attention away from the display, i.e., the focus of attention, thus slowing responses. This “joint distraction” might be related to the functional connectivity of the FEF with occipital regions, associated with the selection of the relevant location, which is more pronounced for gaze than arrows in the right hemisphere. This process could be due to the social properties of gaze stimuli. As the congruent gaze stimuli divert attention away from the task in order to discover what the eyes are looking at and attending to, further processing and reorientation is required to return to the task.

Overall, the whole-brain functional connectivity analysis showed larger brain coactivation differences between responses to congruent and incongruent arrow vs. gaze stimuli. When participants saw an incongruent arrow, the right FEF coactivated with a distributed set of regions in the contralateral hemisphere. This brain response was observed when participants had to resolve the conflict generated by an incongruent arrow (e.g., presented on the right but pointing left).In contrast, incongruent gaze trials were solved without this increased coactivation with the left hemisphere. Two possible explanations have been proposed for this dissociable mechanism we detected for resolving conflict caused by arrows and gaze: 1) Incongruent gaze trials cause less conflict because the location of the stimulus is not considered relevant for the task, and therefore, only one spatial location is prioritized (the location the gaze is directed at) (Hommel, 2004, 2019). It is important to note that some conflict was detected, as the right supramarginal and angular gyrus were more strongly connected with occipito-temporal regions for incongruent than congruent trials for both arrows and gaze. However, the conflict produced by gaze was resolved within one cerebral hemisphere. 2) According to some psychological explanations of the RCE (Edwards et al., 2020; Marotta et al., 2018), incongruent gaze trials cause less conflict because the gaze directs attention to the central fixation point, where the participant is looking at, eliciting "joint attention". Incongruent arrows, on the other hand, direct attention to the opposite hemifield. This hypothesis is consistent with the neural data observed. Incongruent arrows direct attention to the opposite hemifield, which is related to the increase in functional connectivity between the right FEF and the opposite hemisphere; while incongruent gaze direct attention to the center, not to the opposite hemifield, and therefore, the functional connection of the right FEF with the opposite hemisphere is not needed.

Note that both explanations assume that the functional connectivity of the right FEF and the opposite hemisphere reflects attention to both sides of space, while the functional connectivity of the right FEF and the ipsilateral hemisphere reflects attention to only one side of space. This assumption is based on the observation of Ramsey et al. (2016), who reported that acute neglect (in which attention is highly biased to one side of space) is characterized by increased resting state functional connectivity of the right parietal cortex with the ipsilateral hemisphere, and decreased functional connectivity with the opposite hemisphere. However, after neglect recovery (and therefore, when participants are able to attend to both hemifields), the right parietal cortex recovered the functional connectivity with the contralateral hemisphere.

The present fMRI results complement those observed in a recent EEG study (Marotta et al., 2019) using a spatial interference paradigm. The authors also observed shared and dissociable mechanisms for spatial conflict resolution for gaze and arrows in early perceptual stages of processing (shared mechanism: P1, N1, and N170) and late stages of processing (dissociable mechanism: N2 and P3). The present results go a step further, unveiling the brain regions associated with each of these mechanisms.

7.4 Conclusions

In conclusion, our results suggest that the spatial conflict elicited by gaze and arrow stimuli share some common mechanisms: increased functional connectivity of ventral attentional regions with the ipsilateral occipito-temporal cortex during incongruent compared to congruent trials, and increased functional coupling between the FEF and the ipsilateral occipital cortex during congruent as compared to incongruent trials. The latter effect was more pronounced for gaze than arrow targets in the right hemisphere. Besides, dissociable effects were also observed: incongruent arrow targets increased the functional connectivity between the right FEF and the opposite hemisphere, an effect that was not observed with gaze stimuli. These results are consistent with explanations that link the RCE to processes of joint distraction on congruent trials and joint attention on incongruent trials, linking these processes to the functional connections of the dorsal and ventral attentional networks and their interactions with face and object selective regions of the occipital and temporal cortex.

Data/code availability statement

Readers seeking access to the data and experimental materials should contact the author Cristina Narganes-Pineda (cnarganes@ugr.es). Data is also available in the Open Science Framework repository (https://osf.io/y8qsu/)

Ethics statement

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical guidelines laid down by the University of Granada, in accordance with the ethical standards of the 1964 Declaration of Helsinki (last update: Seoul, 2008) and was part of the research project (PSI2017-84926-P) approved by the University of Granada Ethical Committee (536/CEIH/2018). Informed consent Informed consent was obtained from all individual participants included in the study.

Declaration of interest

The authors have no conflict of interest to disclose.

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GENERAL DISCUSSION

CHAPTER 8. General discussion and conclusions

Research regarding social attention explores how spatial attention is allocated to biologically relevant stimuli. These studies have focused on exploring, on the one hand, how attention is oriented to and from the gaze and, on the other hand, how attention triggered by biologically relevant directional stimuli (such as gaze) is similar or can be differentiated from other directional stimuli, such as arrows.

When social and non-social cues have been compared using variations of the spatial orienting paradigm, subtle or no behavioural and neural differences have been observed, leading to the conclusion that the attentional orientation generated by both cues is equivalent, maybe as a consequence of a domain-general attentional orientation (Callejas et al., 2014; Chacón-Candia, Román-Caballero, et al., 2023).

However, recent research has revealed qualitative differences between social and non-social stimuli through precisely targeted experimental designs. In particular, these qualitative differences emerge when the processing of directional information extends beyond simple attentional orientation tasks (Bayliss et al., 2006; Gregory & Jackson, 2017; Marotta et al., 2012). As Birmingham and Kingstone (2009) noted, "*the general intuition that eyes are special is correct but the cueing paradigm may not be measuring what makes eyes distinct from arrows*". As described in the Introduction to this doctoral thesis, the classical spatial orienting paradigm (cueing/gaze-cueing paradigms) has not been able to capture the differences between the social and non-social cues because both cues have the same ability to orient attention and communicate directional information, doing so in a similar fashion (Chacón-Candia, Román-Caballero, et al., 2023; Gibson & Kingstone, 2006).

Therefore, some research has used a qualitative approach to study the differences in attentional effects between social and non-social stimuli. During this doctoral thesis, we used the spatial interference paradigm that has shown differences in spatial congruency effects between arrow and gaze stimuli (Cañadas & Lupiáñez, 2012; Marotta et al., 2018a). In this paradigm, arrows and gaze stimuli are not just cues that orient attention, but target stimuli requiring a response. Taking into account the attributes of the qualitative paradigms described in the Introduction, it seems that behavioural and neural differences start to emerge when information processing goes beyond simple orienting.

This dissertation is primarily interested in furthering our knowledge about the cognitive and neural mechanisms of social attention. Specifically, the cognitive and neural mechanisms that would underlie the standard congruency and RCE generated by arrows and gaze, respectively, when using the spatial interference paradigm. The following section summarises the most important results related to the main and specific objectives of this doctoral thesis, described in Chapter 4.

8.1 Summary of empirical evidence presented in the thesis

To accomplish the general aim of studying the attentional mechanisms triggered by social stimuli, such as gaze, and directly comparing them with other non-social stimuli, such as arrows, we conducted three studies using a qualitative approach, in which we use a variation of the spatial interference paradigm.

In the **first study** of this thesis (Chapter 5), we explored the nature of the attentional processes underlying the dissociation in spatial congruency effects between social and non-social stimuli. Throughout three experiments, we used an intra-block design, where the type of stimulus changed on every trial, allowing us to eliminate the possibility that participants were using a different global strategy to resolve the conflict for each stimulus type. All three experiments replicated the original results, showing a classical congruency effect with arrows (faster RTs for congruent compared to incongruent trials) and a RCE for gaze (faster RTs for incongruent compared to congruent trials). The intra-block design allowed us to study the congruency sequence effects (CSE), with the aim of examining whether this CSE elicited by gaze and arrows generalized from one stimulus to another or, on the contrary, if the CSE was specific to each type of stimulus. This design would therefore answer the question of whether the attentional orienting produced by gaze and arrows rely on the same (generalization of CSE) or different attentional mechanisms (non-generalization of CSE). *Experiment 1* showed standard CSE for successions of arrow trials, with a decreased magnitude of the congruency effect after incongruent arrow trials (compared to congruent arrow trials). We also observed a reversed CSE for successions of gaze trials, with an increased RCE after incongruent gaze trials (as compared to congruent gaze trials). Surprisingly, this pattern of results occurred regardless of the type of stimulus presented on the preceding trial (arrow-gaze or gaze-arrow), and therefore, regardless of the experienced conflict (e.g., increased arrow congruency effects were observed after congruent arrows or congruent gaze trials). This demonstrates, for the first time in literature, that congruency effects can decrease after positive outcomes (e.g., in arrow trials preceded by an incongruent gaze trial). These results indicate that CSEs are generalised from one stimulus to another. Moreover, the CSEs are driven by stimulus congruency rather than by the overall efficiency of previous performance (trials with faster or slower RTs, which are different for arrows and gaze trials). In addition to this shared effect, another effect should be responsible for the opposite cse which occurs in successive trials of the same type of stimulus, and it is therefore hypothesised that could exist an additional specific effect for gaze stimuli that would counter the shared effects of spatial congruency, ultimately generating the reverse congruency effect. *Experiment 2* replicated all the findings of *Experiment 1*. Finally, *Experiment 3* revealed that stimuli belonging to the same category showed equivalent performance related to their category. I.e. for non-social stimuli, we observed standard CSE for arrow trials following word trials (or vice versa). For social stimuli, we observed reversed CSE for gaze trials following face trials (or vice versa). Importantly, the same pattern of CSE was obtained regardless of the target category (same or different) presented in the preceding trials, reflecting the same pattern of cross-conflict sequential effects trials, but in opposite directions.

In the **second study** (Chapter 6), we sought to examine the specific mechanism responsible for the RCE that occurs with gaze stimuli. Hence, we tested the eye contact hypothesis, which postulates that participants are faster on incongruent trials (as compared to congruent trials) because in these trials the eyes are looking "at the participant". If eye contact was the cause of the RCE, it should be observed even in implicit tasks (in which participants respond to a dimension different to space, e.g. colour). In the explicit version (*Experiment 1*), where participants discriminated the direction of stimuli, opposite congruency effects between arrows and gaze occurred, in agreement with the original results (Cañadas & Lupiáñez, 2012; Marotta et al., 2018a). These findings were replicated even when verbal responses were required in *Experiment 3*. In the implicit version (*Experiments 1 and 2*), where participants discriminated the colour of the stimuli, no congruency effects were found either with arrow stimuli or gaze stimuli. There were also no congruency effects when verbally responding to the implicit task (*Experiment 3*). The absence of congruency effects in the implicit task suggests that the direction of the arrow and gaze stimuli does not affect behaviour unless explicitly processed. Furthermore, the opposite congruency effects between arrows and gaze seem to be unrelated to spatial and motor (Simon effect and response compatibility) components related to response type. The fact that the RCE with eye-gaze stimuli was absent in the implicit task, both when the response was manual and when it was verbal, is not consistent with the eye-contact hypothesis, as eye contact still occurs in implicit and verbal tasks.

Finally, in the **third study** (Chapter 7) we explored the neural mechanisms associated with attentional orienting and congruency effects elicited by non-social (arrows) and social stimuli (gaze) using the spatial interference paradigm. To this purpose, we adapted the spatial interference paradigm for an fMRI experiment and explored both shared and dissociable neural mechanisms related to arrows and gaze. Shared mechanisms were observed in ventral attentional regions: When participants faced an incongruent (as compared to congruent) trial, temporo-occipital regions were more strongly coupled for both arrows and gaze. This evidence suggests the existence of some domain-general attentional processes that respond to stimulus directionality regardless of whether the stimulus is social (gaze) or non-social (arrows). In addition, we observed dissociable neural mechanisms between both stimuli in the right hemisphere: the right FEF was more strongly coupled with the occipital cortex for congruent than incongruent trials, and this effect was larger for gaze than arrow stimuli. Moreover, spatial interference produced by incongruent (as compared to congruent) arrows was associated with increased functional coupling between the right FEF and a set of fronto-parietal regions in the left hemisphere. This result was not observed for incongruent (as compared to congruent) gaze stimuli. These findings reveal some of the neural networks associated with spatial conflict resolution that are shared between gaze and arrow trials, as well as an additional set of regions that are differentially involved in the processing of each stimulus.

Across all studies, there was a general slowdown in responses to gaze as compared to arrow stimuli. This pattern of results is usually found in other studies that used gaze and arrow as cues or targets (Fan et al., 2018; J. K. Hietanen et al., 2006; Marotta et al., 2018a; Nummenmaa & Hietanen, 2009; Qian et al., 2017; Vlamings et al., 2005). We consider that it is relevant to wonder whether these differences in RT between the two stimuli might somehow affect the pattern of results and the observed effects. In general terms, we have explained this result by the social meaning and perceptual complexity of gaze stimuli, which may produce larger attentional capture.

The social meaning explanation may be supported by studies that have found slower responses for human-generated cues as compared to the same computer-generated cues (e.g. attribution of social meaning, see Gobel et al., 2018). In general, there is widespread evidence for the attribution of social meaning to gaze stimuli, even in simple laboratory tasks (Jording et al., 2019; for review, see Dalmaso et al., 2020b). This attribution of meaning could lead to longer RTs for gaze stimuli; however, it is difficult to estimate the influence of longer RTs to gaze to the RCE.

The effect of the perceptual complexity of gaze stimuli has also been studied in the spatial interference paradigm presenting a non-socially complex stimulus (inverted triangles). The results showed equivalent RTs between eye trials and inverted triangle trials, while preserving the opposite congruency effects between the two stimuli (Cañadas & Lupiáñez, 2012). Other two studies seem to find that the interaction between congruency and stimulus type is maintained even when stimulus complexity is partially controlled for (Román-Caballero et al., 2021b). Therefore, the differences between gaze and arrow stimuli seem to be due to the social meaning attributed to the eyes. Although we cannot conclude whether the perceptual complexity of gaze stimuli affects the RCE or not, more research is needed on this topic.

In the following two sections, we will discuss the main results of the three studies in relation to the literature to explain which shared mechanisms are involved between arrows and gazes and which mechanisms are different and stimulus-specific.

To do so, we should consider the different cognitive processes that take place when faced with the spatial interference task, in which participants respond to a relevant dimension (stimulus direction) while ignoring an irrelevant dimension (stimulus location). Each one of these processes can be shared or not between both stimuli:

1. Processing of the spatial location in which the stimulus is presented (irrelevant dimension).

2. As participants' task is to determine in which direction the stimuli are pointing or looking at, the direction to which the stimulus points at (the relevant dimension) needs to be encoded.
3. A response has to be prepared; given the lateralisation of the stimuli and the response, the response can be compatible or incompatible (generating the well-known Simon effect, with congruent or incongruent Simon trials).
4. In this paradigm, another type of stimulus-response compatibility is present, which we have called "response mapping" (some authors have called it "direction Simon", Ansorge, 2003; Zorzi et al., 2003), which consists of the relationship between the direction indicated by the stimuli and the laterality of the response (generating compatible response mapping trials: when the direction of the stimulus and the location of the response match; and incompatible response mapping trials: when the direction of the stimulus and the direction of the response do not match).

The design of this task produces congruent (e.g., right-pointing stimuli presented on the right) and incongruent (e.g., right-pointing stimuli presented on the left) trials. During the task, when faced with an incongruent trial (e.g., right-pointing stimuli presented on the left) participants need to detect and resolve the conflict between the relevant and the irrelevant dimension. If the stimulus is social, other processes, specifically related to gaze, such as gaze following, attentional selection to the location where the eyes are gazing at, as well as social attribution or inference processes, etc., may be additionally triggered.

Throughout these two following sections, we will discuss how some of these processes are common/shared during the processing of gaze and arrows, while other processes are different depending on the type of stimulus. The sum of the contribution of all these processes will result in the opposite congruency effect observed between the two stimuli in the spatial interference task, which we defined as standard congruency effect for arrow stimuli and RCE for gaze stimuli.

8. 2 Common and shared mechanisms between non-social and social stimuli

A common mechanism in the processing of arrows and gaze would be related to the ability of both stimuli to generate a spatial and directional representation of space (Gibson & Kingstone, 2006). These processes could be related to sequential effects (which are often manipulated to study cognitive control or adaptation to conflict), and stimulus-response compatibility effects (Simon effect and response mapping effect).

It is known that congruence effects are modulated by the recent history of conflict, i.e. the conflict experienced in the current trial is increased if the previous trial was incongruent (CSE, Gratton et al., 1992; Schmidt & Weissman, 2014; Weissman et al., 2015). This mechanism represents a form of reactive control (Braver, 2012). Furthermore, in line with the literature (Egner et al., 2007; Kiesel et al., 2007; Verbruggen et al., 2005), it is suggested that CSE could be conflict-specific, i.e. it is observed between consecutive trials that share the same conflict type, whereas it disappears between consecutive trials if the conflict type is different (Funes et al., 2010; Torres-Quesada et al., 2014). In line with these findings, our results from the first study show opposing CSE between social and non-social stimuli, suggesting that the type of conflict would be specific and associated with each type of stimulus (Funes et al., 2010; Torres-Quesada et al., 2014). However, this study revealed two relevant results when examining trials in which the stimulus types were alternated. On the one hand, the fact that the CSE generalises regardless of the previous stimulus type suggests that despite being different stimuli (which generate opposite congruency effects), the type of conflict underlying both stimuli could be the same (Funes et al., 2010). On the other hand, for the first time in the literature of cognitive control, we observed an increase in the congruency effect after outcomes considered to be of low efficacy. For example, after a trial of congruent gaze with a slow and ineffective response, we can observe an increase in congruency effects in an arrow trial. As we discussed in the first study, this pattern of results would not be consistent with classical explanations of cognitive control[2], but rather with an explanation related to control priming (Egner, 2014; King et al., 2012). Having exerted control over a shared component or factor across stimuli, in this case, spatial congruency, primes us to exert control over that same component on successive trials.

A related study by Ciardo et al. (2019) used the gaze/arrow cueing paradigm to study sequential effects (SE). The results showed no differences in trial-to-trial modulations when stimuli were repeated (arrow-arrow or gaze-gaze), producing a similar cueing effect for both cues. Moreover, larger cueing effects were observed after valid trials than after invalid trials, and this result was similar for both stimuli. The same pattern of results appeared in other similar works (Qian, Shinomori, et al., 2012; Qian, Song, et al., 2012). These data contrast with ours because we found

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[2] It is important to note that the nature of the CSEs still generates intense debate, which is beyond the purpose of this discussion (see (Botvinick, 2007; Botvinick et al., 2001; Braem et al., 2019; Egner, 2014; Schmidt, 2013 for more detailed discussions)

opposite CSEs for arrows and gaze in successive trials of the same stimulus. However, Ciardo and Qian's results are compatible with the proposal that attentional effects generated by cueing tasks are similar between arrows and gaze. In Qian et al. (2017), both cues (arrow and gaze) are mixed within the same block, and SEs generalised between the different cues types (gaze-arrow or arrow-gaze). The authors suggested that the sequential processing of trials is a common mechanism in attentional orienting processes. To sum up, these studies demonstrate when arrows and gaze are used as both cues and targets, SEs generalise from gaze to arrows and vice versa, supporting our conclusion about a common and shared mechanism when spatially processing both stimuli.

As mentioned above, another cognitive process that could be common/shared between arrows and gaze is stimulus-response compatibility (Simon effect) (Ansorge, 2003; McKee et al., 2007; Zorzi et al., 2003). We wondered whether this stimulus-response compatibility effect might modulate the observed congruency effects (as it modulates the gaze-cueing effect; (McKee et al., 2007). Our second study observed an equivalent classical Simon effect (stimulus-response location compatibility) between arrows and gaze. Other studies also observed that response location did not differentially interfere with the attentional effects triggered by arrows and gaze (Ciardo et al., 2019; Fan et al., 2018; Masaki et al., 2000).

Another process related to our paradigm that has been studied is the "response mapping" (stimulus direction-response compatibility). Some authors who have studied response mapping (Ansorge, 2003; Zorzi et al., 2003) have suggested that gaze generates a unique spatial code of direction. Nevertheless, these authors did not compare the results for gaze versus other types of stimuli, such as arrows. In the second study of this thesis also investigated the effect of response mapping on congruency effects. In addition to the type of task manipulation (explicit vs. implicit), we introduced a second manipulation related to the response mapping between stimuli direction and the response location. In the explicit task, given the compatible mapping between stimuli direction and the response location (e.g., stimuli pointing left always required a left response), two sources of spatial congruency may have contributed to our measure of the congruency effect. In the implicit tasks, a compatible response mapping was presented on 50% of the trials. For this reason, we analyzed the response mapping as a factor in the combined analysis. Although results showed an overall effect of response mapping, this effect did not affect the crucial interaction between Target Type and Congruence, demonstrating that this effect was similar for eye-gaze and arrow stimuli. This suggests that response mapping (or direction Simon) is not specific for the processing gaze direction, but rather represents another shared component that influences the spatial orientation of both stimuli. Consistent with this view, when the response mapping effect was eliminated in the verbal task (see Experiment 3 of Second Study) the interaction between Target Type and Congruence was observed. This result indicates that these processes could be common and facilitate or hinder the responses to both stimuli, but they are not necessary to observe the congruency effect for arrows or the RCE for gaze.

Electrophysiological data also support the existence of shared and common mechanisms in the processing of arrows and gaze by showing that early ERP components (P1 and N1) are similarly modulated by congruency effects triggered by arrows and gaze using the spatial interference task (Marotta et al., 2019b). Generally, these ERP components (P1 and N1) are related to the early stages of perceptual processing (Luck et al., 2000). In our case they are likely related to spatial attention (Hopfinger & Mangun, 2001), reflecting the automatic processing of the spatial component shared by both stimuli.

Uono et al. (2014) used magnetoencephalography (MEG) to measure the neural activity involved in the shifts in attention triggered by arrows and gaze using a gaze-cueing paradigm. Their results showed that areas of the right ventral fronto-parietal network were similarly activated for both types of stimuli at early intervals (200 ms), which might be related to automatic shifts of attention. Brignani et al. (2009) obtained similar results by showing that arrows and gaze induced early automatic shifts of attention and similar early ERP modulations, however, they considered that these similar ERP modulations were more related to an overlearned association mechanism rather than to an exogenous attentional process.

The similar activation of regions of the right ventral fronto-parietal network for arrow and gaze cues, shown by the studies of Uono et al. (2014) using MEG and Sato et al. (2009) using fMRI, resemble those found in the third study of this doctoral thesis. We observed a stronger functional coupling between occipito-temporal regions (right angular – right IOG and right supramarginal – right MTG/ITG) for incongruent compared to congruent trials, which was independent of stimulus type (arrow or gaze targets). These regions are related to the ventral frontoparietal attentional network, which is involved in reorienting attention towards relevant stimuli (Corbetta & Shulman, 2002; Joseph et al., 2015; Kincade et al., 2005). Even though RTs were not slower for incongruent than congruent gaze stimuli, the former caused some conflict in the brain, which might have been resolved by functional coupling between these regions.

The evidence reviewed in this section suggests the existence of some domain-general attentional processes that respond to stimulus directionality regardless of whether the stimulus is social (gaze) or non-social (arrows). The next section discusses this possible dissociable mechanism between arrows and gaze.

8.3 Dissociable and specific mechanisms of non-social and social stimuli

In our work, the dissociable mechanism associated to the processing of arrows and gaze is expressed, at a behavioural level, as different congruency effects between gaze and arrows. We suggest that gaze should have an additional specific effect that would ultimately trigger the RCE; presumably, this effect would be social in nature (Emery, 2000; Hietanen et al., 2018; Ricciardelli et al., 2002). The mechanism behind this specific gaze effect is still unclear. Some studies have reported clear differences between the processing of arrows and gaze. I.e. Marotta et al. (2012) manipulated attention to space or objects. They observed that while gaze directed attention to the specific spatial location, arrows spreaded attention over the entire object being gazed at. Therefore, gaze seems to focus attention selectively and automatically to a specific location/part of the object looked at rather than simply initiating the orienting of attention, as arrows do. These authors thus distinguished two different forms of attentional selection depending on stimulus type (Chacón-Candia, Lupiáñez, et al., 2023; Marotta et al., 2012).

At the neural level, dissociable mechanisms between arrows and gaze were reported by Marotta et al. (2019) using the spatial interference paradigm. They showed a dissociable mechanism at later stages of processing related to the N2 and P3 components, which mimicked the behavioural results (interaction between congruency and target type). Although these components clearly showed dissociable effects between arrows and gaze, it is difficult to conclude whether these modulations are social in nature or might be related to other processes.

In the third study of this thesis, we also showed dissociable neural modulations related to conflict resolution for arrow and gaze stimuli. These differences were mainly related to the functional connectivity between the right FEF and other regions. To resolve the spatial conflict that occurs on incongruent arrow trials (as compared to congruent arrow trials), the right FEF co-activated with a large set of regions of the left fronto-parietal network, while incongruent gaze trials (as compared to congruent gaze trials) did not. These results might be relevant to highlight that not only gaze might have a special component, since in this case the arrows showed effects that gaze did not show. Similarly, Hietanen et al. (2006) showed that arrow cues require the activation of larger sets of regions compared to gaze cues. The authors proposed that arrow-cueing would activate a network similar to that involved in voluntary attentional orienting, whereas gaze-cueing would activate a network related to involuntary attentional control.

Using versions of the cueing paradigm and comparing orienting to arrows and gaze, most studies reported greater activations for occipito-temporal regions for gaze cues as compared to arrow cues (Engell et al., 2010; Hietanen et al., 2006; Lockhofen et al., 2014). For example, Joseph et al. (2015) found that the ventral attentional system, in particular the TPJ and the inferior parietal lobe, were more activated when participants reoriented attention after the presentation of invalid gaze cues (as compared to valid gaze cues), but not after the presence of invalid arrow cues (as compared to valid arrow cues). In addition, another group of the dorsal attentional network was activated in response to invalid gaze cues (as compared to neutral gaze cues), involving regions of the superior parietal lobe together with the FEFs.

Once we have described the dissociable mechanisms observed between the two stimuli, it would be interesting to discuss the mechanisms underlying these differences. Indeed, our hypothesis across studies is that these different congruency effects between arrows and gaze are based on shared mechanisms between the two stimuli (that would lead to the standard congruency effect) and specific mechanisms (that would lead to RCE, this mechanism being gaze-specific). This hypothesis about the social nature of the RCE is based on studies that demonstrate the social relevance of gaze in social cognition (Capozzi & Ristic, 2018; Emery, 2000; Frischen, Bayliss, et al., 2007; Stephenson et al., 2021).

If the RCE is based on a gaze-specific social mechanism, it should be affected by variables related to gaze following, eye contact, automatic attribution of intentions or processes related to the theory of mind. This idea has been confirmed by studies demonstrating that emotional expressions modulate the RCE (Steve Jones, 2015; Torres-Marín et al., 2017). Moreover, these emotional modulations are not found in participants with autistic characteristics (Marotta et al., 2022).

There are three main theoretical explanations for the gaze-specific mechanism responsible for RCE: 1) *Eye-contact hypothesis*, 2) *Join attention hypothesis*, and 3) *Joint distraction hypothesis*.

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

The results from the second study of this thesis did not support the *eye contact hypothesis* as an explanation of the RCE. When participants did not respond to the direction of the stimuli in an implicit task (which consisted of a colour discrimination task), we did not observe any congruency effect, neither with the arrows nor with gaze. Therefore, RTs were comparable for congruent and incongruent gaze trials even if eye contact was still present in the task. As previous studies have observed that eye-contact also occurs when gaze is incidentally processed (Adolphs, 2009; Lieberman, 2007; Sato et al., 2016; Stein et al., 2011; Xu et al., 2011), we interpreted the lack of RCE with gaze as evidence against the eye contact explanation of the RCE.

Our neuroimaging data do not support either the *eye contact hypothesis*. According to some studies, the processing of direct gaze requires the involvement of regions such as the STS, the FG, the orbitofrontal cortex, and the bilateral amygdala (Calder et al., 2002; Carlin & Calder, 2013; Pelphrey et al., 2004; for an extensive review see Senju & Johnson, 2009). Whereas the processing of averted gaze requires the involvement of regions such as the STS, intraparietal sulcus, regions of the parietal cortex, as well as temporal regions, jointly with the TPJ

(Grosbras et al., 2005; Hoffman & Haxby, 2000; Itier & Batty, 2009; Nummenmaa & Calder, 2009). If we consider incongruent trials as direct gaze and congruent trials as the averted gaze, our results seem more related to the perception of averted gaze rather than direct gaze. In fact, we did not find greater activations in either condition in the amygdala, which has been shown to be a crucial region in the eye contact effect. Interestingly, our activations for both congruent and incongruent gaze trials are observed in clusters of parieto-temporo-occipital regions, and the superior frontal, which might be more related to perceiving averted gaze or gaze following.

Once it has been demonstrated that the specific gaze mechanism responsible for RCE is not related to the *eye contact hypothesis*, other possible hypotheses related to the theory of mind and the ability of the gaze to trigger inferential processes about the intentions and interests of others are proposed: *Joint attention* and *Joint distraction hypothesis*. According to several authors, gaze perception is an indispensable first-order cognitive process in the construction of social cognition, in other words, detecting, discriminating and interpreting the direction of a gaze would be low-level requirements essential to generate other processes of social cognition considered to be high-level, such as the theory of mind (for review see Stephenson et al., 2021).

The *joint attention hypothesis* (Cañadas & Lupiáñez, 2012; Edwards et al., 2020), proposes that participants and the gaze stimulus share the same focus of attention (i.e. fixation point) when an incongruent trial is presented, generating an effect of joint attention towards the fixation point. It is well established that a simulated joint attention episode facilitates the processing of elements of the joint attention scenario (Edwards et al., 2015). However, although this explanation seems plausible for incongruent gaze trials, a recent study (Aranda-Martín et al., 2022) has reported that the RCE is not observed until around 12 years of age, with 4-year-old children showing a standard congruency effect with both arrow and gaze stimuli. These findings do not support the joint attention explanation of the RCE because joint attention emerges at around 6 months and develops until the age of 3 years (Mundy et al., 2007).

In the first study of this thesis, we proposed another possible hypothesis, the *joint distraction hypothesis* related to the processing of gaze congruent trials, which would hinder their processing and consequently increase RT. The idea is that congruent gaze trials direct attention away from the task towards an unclear spatial location, and participants would automatically follow this gaze; in other words, congruent gaze trials could initiate an act of attentional selection towards a specific-location, which would lead to distraction, generating longer RTs. These processes could be related to the automatic social inferences we make from the gaze of the other people (Capellini et al., 2019; Dalmaso et al., 2020b; Shepherd, 2010).

Both the *joint attention hypothesis* for incongruent gaze trials and the *joint distraction hypothesis* for congruent gaze trials would be plausible, but nowadays we do not have enough data to strongly support one over the other. Our fMRI data could be explained by both hypotheses.

The *joint attention hypothesis* explains the processing on incongruent trials. In our fMRI data we observed a stronger connectivity of the right FEF with left fronto-parietal regions for incongruent vs. congruent trials, but only for arrow stimuli. We proposed that both hemispheres might be needed after an incongruent arrow trial because the stimulus is presented in one hemifield, pointing to the other hemifield. But if incongruent gaze stimuli orient attention to the center (causing "joint attention"), only one hemifield is being processed, and conflict is resolved without the involvement of the left hemisphere.

The *joint distraction hypothesis* might be related to the processing of gaze congruent trials, which were associated to increased functional connectivity of the FEF with occipital regions, associated with the selection of the relevant location, which is more pronounced for gaze than arrows in the right hemisphere. It is possible that the FEF biases the processing of goal-relevant stimuli and locations in the visual cortex (Corbetta & Shulman, 2002). Congruent gaze stimuli would require further processing and reorientation to return to the task. When participants follow the gaze, they do not only initiate an act of attentional orienting but also initiate an act of attentional selection towards the location where the eyes are looking at, which takes them outside the task and distracts them, increasing RT on these trials, which would not occur with congruent arrow stimuli.

8.4 Open questions and future directions

Despite the contributions of this thesis to the study of social attention and, in particular, to study the nature of the qualitative differences between arrows and gaze, this approach to the study of these differences is still recent in the literature on social attention. Hence, many unanswered questions need further research. In this section, I will briefly describe some ideas for future research. I have decided to divide this section in the same way as the previous one to facilitate the reading.

Future research related to the common mechanisms for processing social and non-social stimuli

Studying how participants adapt to the conflict resulting from the task has allowed us to study the processes underlying the opposing congruency effects between arrows and gaze. We know that the congruency effect can be reduced by applying control through two effects, the CSE and the congruency proportion (CP) effect (Carter et al., 2000; Torres-Quesada et al., 2014). The PC effect involves manipulating the proportion of congruent and incongruent trials. Similar to the CSE study, the study of PC could provide new data on this common mechanism, by investigating the proactive-reactive nature of the conflict. On the other hand, the study of processes that modulate spatial conflict could be key to dissociating which mechanisms are the product of the standard congruency effect, which mechanisms generalise between stimuli, and which mechanisms are dissociable or specific for gaze (Román-Caballero et al., 2021b).

Future research related to the dissociable mechanism for processing of social and non-social stimuli

The perceptual complexity of the gaze stimulus compared to the arrow is a fact. However, this complexity resides not only at the perceptual level but also at the level of interpretation. We tend to attribute social intention to gaze stimuli automatically, and this increases effect as the eyes become more realistic. In general, we assume this social interpretation underlies the RCE. However, with the available data, it is not possible to refute that perceptual complexity can affect the RCE. Therefore, future research would need to study or control for this, trying to match the two study conditions.

It is proposed that the nature of RCE is due to a socially specific mechanism of gaze. However, most of the existing studies have yet to modulate this social component directly. Because the essence of this paradigm consists of comparing arrows and gaze, modulating the social component in both stimuli at the same time is difficult (e.g. we can modulate emotion in gaze and observe how that affects RCE, but we cannot modulate emotion in an arrow, Marotta et al. (2022). Based on the studies of Gobel et al. (2018), it was suggested that visual attention can be guided by the mental representation of its social relevance. We propose that if participants are led to believe that the direction of arrows is generated by a partner they are "playing" with, while a computer still generates the direction of gaze, we might observe the RCE for arrows. This could be evidence in favor of the social nature of RCE.

Future studies related to the neural mechanisms underlying RCE

The third study in this thesis is the first one in the literature to explore the neural basis underlying the differences in congruency effects between arrows and gaze with the spatial interference paradigm. Although the results have been promising, showing findings in line with the behavioural data and electrophysiological evidence, we used classical univariate analysis to assess the brain regions involved in the processing of gaze and arrows. To improve the interpretations of the neuroimaging data, it would be interesting in future studies to use multivariate pattern analysis (MVPA; Haxby et al., 2014) to observe the activation pattern of each of the study conditions. By training a classifier, we could observe which brain areas represent the conflict in a similar way for arrows and gaze, and which brain regions represent the conflict differently for each type of stimulus.

Based on the functional connectivity fMRI results, future studies could test the causal role of certain brain areas, both in the common attentional mechanism between both stimuli that cause the standard congruency effect, and in the gaze-specific mechanisms that cause the RCE. For this purpose, transcranial magnetic stimulation (TMS) could be used in regions such as the TPJ or FEF to test their causal role in the standard congruency effect and RCE.

8.5 Conclusions

The findings of the present thesis support the existence of qualitative differences between arrow and gaze stimuli when used as targets instead of cues in a spatial interference task. The most relevant results suggest that common and dissociable mechanisms between arrow and gaze stimuli underlie the standard congruency effects observed with arrows and the RCE observed with the gaze.

Neuroimaging data support these findings by showing shared activations between arrows and gaze in functional connectivity between regions of the ventral attentional network and ipsilateral temporo-occipital regions. As well as dissociable activations between arrow and gaze stimuli, with functional connectivity of the right FEF with ipsilateral occipito-temporal regions for gaze stimuli and a functional coupling of the right FEF with extended regions of the contralateral dorsal attentional network for arrows.

The common mechanisms in the processing of arrows and gaze would be related to spatial orientation and conflict resolution components, which would cause the standard congruency effect, which is only observed with arrows, but that we proposed contributes to the processing of both arrows and gaze. The dissociable mechanism would be related to additional gaze-specific processes that would be responsible for the RCE. The nature of RCE could be related to the social meaning of gaze. Gaze not only orients us in space but also communicates information about our focus of interest, our intentions or our thoughts, among others. This thesis also contributes to discerning between the different theoretical explanations for the RCE. We test the eye contact effect hypothesis, one of the most widely used hypotheses to explain the RCE, although our data did not support this explanation. We discussed other plausible hypotheses as responsible for RCE.

This thesis aimed at increasing the knowledge about social attention and attentional-orienting processes triggered by social and non-social stimuli. Although this doctoral thesis can be considered basic research, understanding the basic cognitive and neural processes of social attention is essential to form the basis of more applied research. In fact, the study of the attentional mechanisms related to gaze direction processing could have important clinical and rehabilitation implications in populations with altered gaze processing patterns such as autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), and psychiatric disorders (Marotta et al., 2014). Gaze perception is an essential step in social interactions and in the development of various communication and social cognition skills such as the theory of mind (Stephenson et al., 2021).

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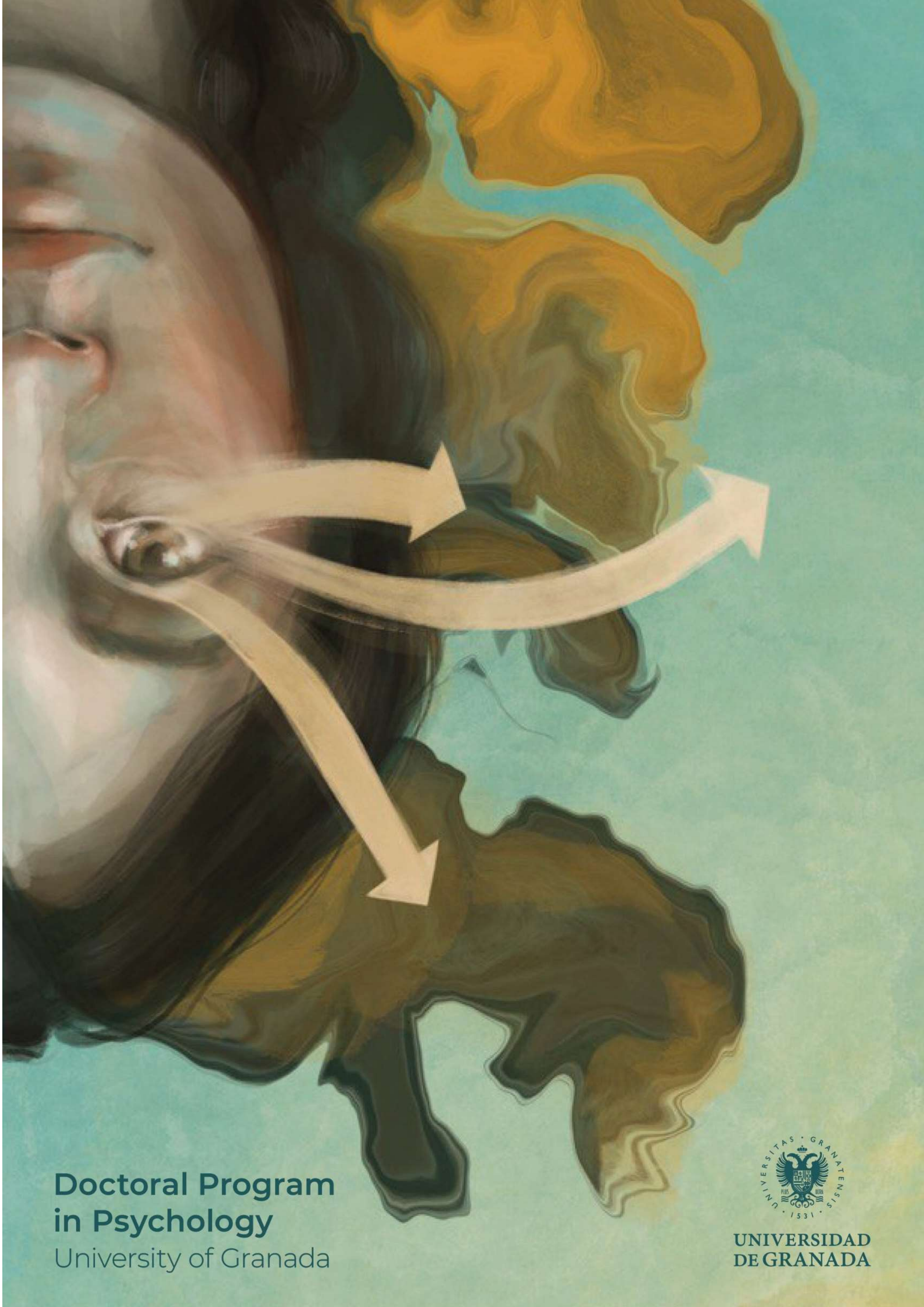

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