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Attentional Mechanisms Underlying Social and Non-Social Attentional Orienting

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Attentional Mechanisms Underlying Social and Non-Social Attentional Orienting

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ABSTRACT

Visual attention, and in particular social attention, constitutes a multi-level system that prioritizes goal-relevant information while suppressing distractors via context-dependent weighting that amplifies relevant signals and attenuates irrelevant input. Within this framework, gaze occupies a central role: it not only automatically orients the observer's attentional focus toward potentially informative sources but also conveys intention and social relevance, integrating perceptual, attentional, and social-cognitive processes. Among the mechanisms that coordinate this dynamic, two complementary processes are central for this work: the orienting of attention toward potentially informative sources and control processes that resolve competition between visual codes at decision and response levels.

From this perspective, directional stimuli such as gaze and arrows offer an important comparative case. Although both can guide attention, they differ in their perceptual composition and communicative value, providing researchers with two complementary types of stimuli to examine the general and specific mechanisms of attention.

To this end, two main experimental paradigms have been employed; the cueing and the spatial interference paradigms. The first enabled the initial attempts to determine whether attentional orienting induced by gaze differed from that induced by arrows, revealing quantitatively similar effects but qualitative differences. The second offered a more sensitive framework for exploring these divergences by placing directional information in conflict with the spatial position of the stimulus. In these tasks, stimuli are presented at positions that either match or conflict with their directional information, revealing how location and direction codes interact and setting the stage for this thesis's central puzzle: the divergent congruency patterns for gaze versus arrows.

Despite important advances in spatial interference research, a central uncertainty remains: why do gaze targets frequently produce a reversed congruency effect (RCE), with faster responses on incongruent trials (direction and position in conflict), whereas arrows typically yield the standard congruency effect (SCE), with faster responses on congruent trials (direction and position match)? This divergence has sustained a debate between social accounts that grant gaze a privileged status and domain-general accounts

proposing that reversal arises from conflict dynamics shaped by perceptual constraints and control.

This thesis addresses this debate by examining the boundary conditions under which reversal arises and how its distributional dynamics differ for gaze versus non-social targets. It combines large-scale reanalyses with two preregistered studies using arrows designed to mimic gaze-like constraints. Studies 1–2 applied conditional accuracy functions (CAFs) and delta functions to published gaze/arrow data to isolate early response dynamic and time-dependent interference. Studies 3–4 manipulate perceptual structure in arrow targets, first by mimicking gaze-relevant features and increasing background complexity, and then by applying visual masking, to introduce face-like surrounding complexity and test whether non-social stimuli can reproduce gaze-like reversal dynamics.

Within the distributional analysis, arrows showed typical non-social patterns: among the CAF fastest responses, accuracy reductions concentrated on incongruent trials, reflecting an automatic response capture mechanisms (i.e., a high proportion of responses are likely selected by spatial location rather than direction), and delta functions were positive and slightly decreasing across quantiles. Gaze diverged on both fronts: CAFs revealed accuracy reductions for both congruency conditions, with congruent trials showing even lower accuracy at short latencies, and deltas were negative and became more negative with RT, indicating an emergent, dynamic reversal. These results suggest that gaze does not merely disrupt spatial interference but reconfigures the timing and balance between automatic activation and response selection, creating conditions under which reversal becomes likely.

Altering arrows to mimic iris-sclera polarity and adding complex backgrounds reduced interference and attenuated early capture but did not yield an RCE, neither at the mean level analyses nor at the distributional level. By effectively masking directional information, however, arrows shifted from SCE to a reliable RCE with gaze-like distributional profiles. Thus, non-social stimuli can elicit reversal when specific perceptual constraints interact with directional information in the same functional way that gaze naturally does.

Across these findings, three implications follow. First, the reversal does not require exclusively social mechanisms. The RCE appears to emerge from the interaction between automatic response processes, potentially modulated by the elements surrounding directional information, and control processes of the cognitive system, which adjust their onset and intensity according to both their own capacities and the characteristics of the stimulus. Second, gaze may naturally instantiate these conditions: its complex morphology and communicative value likely provide multiple signals that compete with each other and are rapidly registered, reconfiguring conflict dynamics when circumstances allow. Third, arrows masked with elements resembling their own structure can approximate the visual effects produced by faces, reproducing reversal patterns similar to those of gaze and suggesting that what gaze contributes intrinsically can be recreated through non-social stimuli.

These findings reframe the RCE as a domain-general phenomenon that emerges from the interaction among stimulus properties, task demands, and the dynamics of the system that processes them. In this context social stimuli such as gaze are effective in generating the reversed dynamics not because they invoke a categorically distinct mechanism, but because their perceptual and communicative complexity, when embedded in a context that disrupts typical processing, promotes the emergence of non-neutral signals that interact with directional information and modulate control mechanisms.

This reframing bridges theories of social attention with a broader framework grounded in conflict dynamics. It also provides a plausible explanation for the emergence of negative delta values, for why congruent responses can become disproportionately error-prone at the fastest latencies, and for how perceptual manipulations (e.g., masking) reshape the temporal course of conflict and its inhibition until reversal occurs.

In sum, the account describes boundary conditions for the RCE and yields testable predictions. It links social-attention findings to conflict-dynamics accounts and proposes concrete tests, combining behavioral and neurophysiological measures with computational models, to predict when and how the RCE should appear. It also positions gaze stimuli on a continuum of complex objects that, depending on the setting, are processed by domain-general mechanisms.

RIASSUNTO

L'attenzione visiva, e in particolare l'attenzione sociale, costituisce un sistema multilivello che dà priorità alle informazioni rilevanti mentre sopprime i distrattori mediante una pesatura contestuale che amplifica i segnali pertinenti e attenua quelli irrilevanti. All'interno di questo quadro, lo sguardo occupa una posizione centrale: non solo orient automaticamente il focus attentivo dell'osservatore verso fonti potenzialmente informative, ma trasmette anche intenzione e rilevanza sociale, integrando sistemi percettivi, attentivi e qualli legati alla cognizione sociale. Tra i meccanismi che coordinano questo sistema, due processi complementari sono centrali: l'orientamento del focus attentivo verso fonti potenzialmente informative e i processi di controllo che risolvono la competizione tra codici visivi ai livelli di decisione e di risposta.

Da questa prospettiva, stimoli direzionali come lo sguardo e le frecce offrono un caso comparativo importante. Sebbene entrambi possano guidare l'attenzione, differiscono nella loro composizione percettiva e nel loro valore comunicativo, offrendo ai ricercatori due tipi di stimoli complementari per esaminare i meccanismi generali e specifici dell'attenzione.

A questo scopo stati impiegati principalmente due paradigmi sperimentali: quallo del cueing e quello dell'interferenza spaziale. Il primo ha consentito i tentativi iniziali di distinguere se l'orientamento attentivo indotto dallo sguardo differisse da quallo indotto dalle frecce, rivelando effetti quantitativamente simili ma possibili differenze qualitative. Il secondo ha offerto un quadro più sensibile per esplorare tali divergenze, ponendo l'informazione direzionale in conflitto con la posizione spaziale dello stimolo. In questi compiti, gli stimoli sono presentati in posizioni che coincidono o entrano in conflitto con la loro informazione direzionale, rivelando come interagiscono i codici di localizzazione e di direzione e preparando il terreno per il problema centrale di questa tesi: i pattern di congruenza divergenti tra sguardo e frecce.

Nonostante i notevoli progressi della ricerca sull'interferenza spaziale, persiste un'incertezza centrale: perché gli stimoli di sguardo producono spesso un effetto di congruenza inversa (RCE), con risposte più rapide nelle prove incongruenti (direzione e posizione in conflitto), mentre le frecce tendono a generare un effetto di congruenza standard (SCE), con risposte più rapide nelle prove congruenti (direzione e posizione

coincidenti)? Questa divergenza ha sostenuto un dibattito tra spiegazioni di carattere sociale, che attribuiscono allo sguardo uno status privilegiato, e spiegazioni di dominio generale, secondo cui l'inversione emerge da dinamiche di conflitto modulate da vincoli percettivi e processi di controllo.

Questa tesi affronta il dibattito esaminando le condizioni limite sotto le quali l'inversione emerge e come la sua dinamica sottostante differisca tra lo sguardo e stimoli non sociali. Il lavoro combina rianalisi su larga scala con due studi sperimentali preregistrati che impiegano frecce progettate per imitare aspetti simili a quelli dello sguardo. Gli Studi 1–2 hanno applicato la conditional accuracy function (CAF) e analisi di delta function a dati pubblicati su sguardo e frecce per isolare la dinamica delle risposte rapide e la dinamica temporale dell'interferenza. Gli Studi 3–4 hanno manipolato la struttura percettiva delle frecce, prima imitando caratteristiche rilevanti dello sguardo e aumentando la complessità dello sfondo, poi applicando mascheramento visivo, per introdurre una complessità contestuale simile a quella del volto e verificare se stimoli non sociali possano riprodurre dinamiche sottese all'inversione simili a quelle dello sguardo.

Nelle analisi di distribuzione, le frecce hanno mostrato pattern tipici di stimoli non sociali: tra le risposte più rapide nelle CAF, le riduzioni di accuratezza si sono concentrate nelle prove incongruenti, riflettendo un meccanismo di cattura automatica della risposta (cioè una quota elevata di risposte selezionate in base alla posizione più che alla direzione), e le curve delta (*delta plots*) sono risultate positive e leggermente decrescenti lungo i quantili. Lo sguardo si è mostrato diverso nei due fronti: le CAF hanno rivelato riduzioni di accuratezza in entrambe le condizioni di congruenza, con le prove congruenti che mostravano accuratezza ancora minore nei tempi di reazione (TR) più rapidi; inoltre, i valori delta erano negativi e diventavano più negativi con l'aumento dei TR, indicando un'inversione emergente e dinamica. Questi risultati suggeriscono che lo sguardo non solo introduce interferenza spaziale, ma riconfigura il dispiegarsi temporale e l'equilibrio tra attivazione automatica e selezione della risposta, creando le condizioni in cui l'inversione diventa probabile.

D'altra parte, modificare le frecce per imitare la polarità iris–sclera e aggiungere sfondi complessi ha ridotto l'interferenza spaziale e attenuato la cattura automatica, ma non ha prodotto un RCE, né a livello delle medie né a livello distribuzionale. Al contrario,

mascherando in modo efficace l'informazione direzionale, le frecce sono passate da un SCE a un RCE, con profili distribuzionali simili a quelli dello sguardo. Pertanto, gli stimoli non sociali possono facilitare l'inversione quando aspetti percettivi specifici interagiscono con l'informazione direzionale, possibilmente nello stesso modo in cui accade naturalmente con lo sguardo.

Da questi risultati emergono tre implicazioni. Primo, l'inversione non richiede meccanismi esclusivamente sociali. Il RCE sembra derivare dall'interazione tra processi di risposta automatici, potenzialmente modulati dagli elementi che circondano l'informazione direzionale, e processi di controllo del sistema cognitivo, che ne regolano l'attivazione e l'intensità in base alle proprie capacità e alle caratteristiche dello stimolo. Secondo, lo sguardo può instanziare naturalmente tali condizioni: la sua complessa morfologia e il suo valore comunicativo probabilmente forniscono segnali multipli che competono tra loro e vengono elaborati rapidamente, riconfigurando la dinamica del conflitto quando le circostanze lo consentono. Terzo, le frecce mascherate con elementi simili alla propria struttura possono avvicinarsi agli effetti visivi prodotti da un volto, riproducendo schemi di inversione simili a quelli dello sguardo e suggerendo che ciò che lo sguardo offre in modo intrinseco può essere ricreato attraverso stimoli non sociali..

Questi risultati riformulano il RCE come un fenomeno di dominio generale che emerge dall'interazione tra le proprietà dello stimolo, le richieste del compito e la dinamica del sistema che le elabora. In questo contesto, gli stimoli sociali come lo sguardo risultano efficaci nel produrre la dinamica dell'inversione non perché attivino un meccanismo categorialmente distinto, ma perché le loro complessità percettiva e comunicativa, inserita in un contesto che interrompe il normale processo di elaborazione, favorisce la comparsa di segnali non neutri che interagiscono con l'informazione direzionale e modulano i meccanismi di controllo.

Questa riformulazione mette in dialogo le teorie dell'attenzione sociale con un quadro più ampio basato sulle dinamiche di conflitto. Inoltre, propone una spiegazione plausibile del perché compaiano delta negativi, del perché le risposte congruenti possano essere sproporzionatamente soggette a errore alle latenze più rapide e di come le manipolazioni percettive rimodellino l'andamento temporale del conflitto e della sua inibizione fino a produrre l'inversione.

In sintesi, il quadro descrive le condizioni limite del RCE e genera predizioni verificabili. Collega i risultati sull'attenzione sociale agli approcci incentrati sul conflitto e sulla sua inibizione e propone test concreti, combinando misure comportamentali e neurofisiologiche con modelli computazionali, per prevedere quando e come dovrebbe manifestarsi il RCE. Colloca inoltre gli stimoli sociali in un continuum di oggetti complessi che, a seconda del contesto, sono elaborati da meccanismi di dominio generale.

RESUMEN

La atención visual, y en particular la atención social, constituye un sistema multinivel que prioriza la información relevante mientras suprime los distractores mediante una ponderación contextual que amplifica las señales pertinentes y atenúa aquellas irrelevantes. Dentro de este marco, la mirada ocupa un lugar central: no solo orienta automáticamente el foco atencional del observador hacia fuentes potencialmente informativas, sino que también transmite intención y relevancia social, integrando sistemas perceptivos, atencionales y aquellos ligados a la cognición social. Entre los mecanismos que coordinan estos sistemas, dos procesos complementarios son fundamentales: la orientación del foco atencional hacia señales potencialmente informativas y los procesos de control que resuelven la competencia entre códigos visuales a nivel de decisión y de respuesta.

Desde esta perspectiva, estímulos direccionales como la mirada y las flechas ofrecen un caso comparativo importante. Aunque ambos pueden guiar la atención, difieren en su composición perceptiva y en su valor comunicativo, lo que permite a los investigadores disponer de dos tipos de estímulos complementarios para examinar los mecanismos generales y específicos de la atención.

Para ello se han empleado principalmente dos paradigmas experimentales: el de *cueing* y el de interferencia espacial. El primero permitió los intentos iniciales por distinguir si la orientación atencional inducida por la mirada difería de la de las flechas, revelando efectos cuantitativamente similares pero posibles diferencias cualitativas. El segundo ofreció potencialmente un marco más sensible para explorar esas divergencias, al situar la información direccional en conflicto con la posición espacial del estímulo. En estas tareas, los estímulos se presentan en posiciones que coinciden o entran en conflicto con su información direccional, revelando cómo interactúan los códigos de localización y de dirección, y preparando el terreno para el problema central de esta tesis: los patrones de congruencia divergentes entre mirada y flechas.

A pesar de los avances importantes en la investigación sobre interferencia espacial, persiste una incertidumbre central: ¿por qué los estímulos de mirada producen con frecuencia un efecto de congruencia revertida (RCE), con respuestas más rápidas en los ensayos incongruentes (dirección y posición en conflicto), mientras que las flechas

suelen generar un efecto de congruencia estándar (SCE), con respuestas más rápidas en los ensayos congruentes (dirección y posición coincidentes)? Esta divergencia ha sostenido un debate entre explicaciones de carácter social, que otorgan a la mirada un estatus privilegiado, y las explicaciones de dominio general, que proponen que la reversión surge de dinámicas de conflicto moduladas por restricciones perceptivas y procesos de control.

Esta tesis aborda este debate examinando las condiciones límite bajo las cuales surge la reversión y cómo su dinámica subyacente difiere entre la mirada y estímulos no sociales. El trabajo combina reanálisis a gran escala con dos estudios experimentales preregistrados que emplean flechas diseñadas para imitar aspectos similares a las de la mirada. Los Estudios 1–2 aplicaron la *conditional accuracy function* (CAF) y análisis de *delta function* a datos publicados de mirada versus flechas para aislar la dinámica entre las respuestas rápidas y la dinámica temporal del efecto de interferencia. Los Estudios 3–4 manipularon la estructura perceptiva de las flechas, primero imitando características relevantes de la mirada y aumentando la complejidad del fondo, y después aplicando enmascaramiento visual, para introducir complejidad contextual similar a la del rostro y comprobar si los estímulos no sociales pueden reproducir dinámicas que subyacen a la reversión semejantes a las de la mirada.

En los análisis de distribución, las flechas mostraron patrones típicos de estímulos no sociales: entre las respuestas más rápidas del CAF, las reducciones en la precisión se concentraron en los ensayos incongruentes, reflejando un mecanismo de captura automática de la respuesta (es decir, una alta proporción de respuestas probablemente seleccionadas por la posición más que por la dirección), y las curvas delta (*delta plots)* fueron positivas y ligeramente decrecientes a lo largo de los cuantiles. La mirada se desvió en ambos frentes: los CAF revelaron reducciones de la precisión en ambas condiciones de congruencia, con los ensayos congruentes mostrando una precisión aún menor en latencias cortas; además, los valores deltas fueron negativos y se volvieron más negativas con el aumento de los tiempos de reacción, indicando una inversión emergente y dinámica. Estos resultados sugieren que la mirada no solo introduce interferencia espacial, sino que reconfigura el despliegue temporal y el equilibrio entre la activación automática y la selección de la respuesta, creando las condiciones bajo las cuales la reversión se vuelve probable.

Por otro lado, modificar las flechas para imitar la polaridad iris–esclera y añadir fondos complejos redujo la interferencia espacial y atenuó la captura de respuesta, pero no produjo un RCE, ni a nivel de medias ni a nivel distribucional. En cambio, al enmascarar eficazmente la información direccional, las flechas pasaron de un SCE a un RCE robusto, con perfiles distribucionales similares a los de la mirada. Por lo tanto, los estímulos no sociales pueden facilitar la reversión cuando restricciones perceptivas específicas interactúan con la información direccional, posiblemente, del mismo modo en que ocurre de forma natural con la mirada.

De estos resultados se desprenden tres implicaciones. Primero, la inversión no requiere mecanismos exclusivamente sociales. El RCE parece emerger de la interacción entre procesos de respuesta automáticos, potencialmente modulados por los elementos que circundan la información direccional, y los procesos de control del sistema cognitivo, que ajustan su activación inicial e intensidad según las propias posibilidades y las características del estímulo. Segundo, la mirada puede instanciar naturalmente estas condiciones: su compleja morfología y su valor comunicativa probablemente proporcionan múltiples señales que compiten entre sí y se registran con rapidez, reconfigurando la dinámica del conflicto cuando las circunstancias lo permiten. Tercero, las flechas enmascaradas con elementos similares a su propia estructura pueden aproximarse a los efectos visuales que produce una cara, reproduciendo patrones de reversión semejantes a los de la mirada y sugiriendo que aquello que la mirada aporta de forma intrínseca puede recrearse mediante estímulos no sociales.

Estos hallazgos replantean el RCE como un fenómeno de dominio general que emerge de la interacción entre las propiedades del estímulo, las demandas de la tarea y la dinámica del sistema que las procesa. En ese contexto, los estímulos sociales como la mirada resultan eficaces para general la dinámica de la reversión, no porque activen un mecanismo categóricamente distinto, sino porque sus complejidad perceptivas y comunicativa, al insertarse en un contexto que interrumpe su procesamiento típico, favorece la aparición de señales no neutras que interactúan con la información direccional y modulan los mecanismos de control.

Este replanteamiento pone en diálogo las teorías de la atención social con un marco más amplio basado en las dinámicas del conflicto. Además, propone una

explicación plausible de por qué aparecen valores delta negativos, por qué las respuestas congruentes pueden ser desproporcionadamente propensas al error en las latencias más rápidas y cómo las manipulaciones perceptivas (p. ej., el enmascaramiento) remodelan el curso temporal del conflicto y su inhibición hasta producir la reversión.

En suma, el marco describe las condiciones límite del RCE y genera predicciones comprobables. Vincula los hallazgos de atención social con los enfoques centrados en el conflicto y su inhibición, y propone pruebas concretas, combinando medidas conductuales y neurofisiológicas con modelos computacionales, para predecir cuándo y cómo debería aparecer el RCE. Asimismo, sitúa los estímulos sociales en un continuo de objetos complejos que, según el contexto, son procesados por mecanismos generales.

Table of Contents

CHAPTER 1. INTRODUCTION 1

1.1. Visual Attention, Spatial Orienting and Control Mechanisms 2

1.2. Experimental Paradigms for Studying Visual Attention 8

1.2.1. The Spatial Orienting Paradigm 8

1.2.2. The Spatial Interference Paradigm 10

1.3. Gaze and Social Attention 14

1.3.1. Gaze as a Social Signal 14

1.3.2. The Gaze-Cueing Paradigm 17

1.4. The Spatial Interference Paradigm in Social Attention Research 20

1.4.1. From Gaze Cueing to Spatial Interference 20

1.4.2. The Reversed Congruency Effect: Characteristics and Modulators 22

1.4.3. Theoretical Accounts of the RCE: Social, Non-Social, and Integrative Perspectives 29

1.4.4. The dual-route framework and the distributional approach 35

CHAPTER 2. MOTIVATION, AIMS, AND OVERVIEW OF THE RESEARCH ... 39

2.1. Motivation & Aims 40

2.2. Overview of the Research 43

CHAPTER 3. EXPERIMENTAL SERIES 49

3.1. Study 1. Exploring the spatial interference effects by social and non-social targets: A conditional accuracy function approach 50

3.2. Study 2. Investigating the gaze-driven reversed congruency effect in the spatial Stroop task: A distributional approach 77

3.3. Study 3. Is the Reversed Congruency Effect Observed with Gaze due to its Social Nature? Analysis of Non-Social Stimuli with Similar Asymmetrical Contrast Features of Eye-gaze Stimuli 105

3.4. Study 4. When Arrows Behave Like Eyes: Reversal of Spatial Stroop Interference by Visual Masking 137

CHAPTER 4. GENERAL DISCUSSION 177

4.1. Summary of Contributions 181

4.1.1. Empirical Contributions 181

4.1.2. Theoretical Contributions 187

4.2. Toward an Account of the Underlying Dynamics of the RCE 201

4.3. Future Directions 204

4.4. Concluding Remarks 207

REFERENCES 209

APPENDICES 255

Appendix A. Supplemental Materials for Study 1 255

Appendix B. Supplemental Materials for Study 2 270

Appendix C. Supplemental Materials for Study 4 276

Appendix D. Pre-Cueing Effects on Spatial Interference 283

Appendix E. Reanalysis of Narganes-Pineda, Chica, et al. (2023), Experiment 3A 288

Appendix F. Congruency Effects During the Initial Trials 290

CHAPTER 1. INTRODUCTION

1.1. Visual Attention, Spatial Orienting and Control Mechanisms

Imagine walking through a busy street: countless colors, movements, and sounds compete for your awareness, yet can effortlessly focus on a friend's wave or a traffic light turning red. This ability to prioritize relevant information while ignoring distraction is made possible by visual attention. Visual attention operates as a control mechanism that filters incoming input and allows only selected portions of the visual field to be processed in depth, while monitoring changes in both external and internal signals (Chun et al., 2011; Narhi-Martinez et al., 2023). This ensures that the most relevant aspects of a scene, those aligned with current goals, expectations, or task demands, receive priority access to perception, memory, and action systems (Carrasco, 2011; Moore & Zirnsak, 2017).

A useful model for understanding these mechanisms is the multi-level system of weights and balances (Narhi-Martinez et al., 2023), in which stimuli exert differential influence on processing and attention dynamically adjusts their relative priority. Stimuli that are visually salient, socially or emotionally relevant, or associated with prior learning may receive stronger weighting (Fenske & Eastwood, 2003; Olivers et al., 2006; B. Wang & Theeuwes, 2018), whereas competing or irrelevant input is down-weighted or suppressed (Gaspelin & Luck, 2018a; Leber et al., 2016).

These weights are determined by a combination of top-down, bottom-up, and experience-based mechanisms (Egeth & Yantis, 1997; Itti & Koch, 2001; B. Wang & Theeuwes, 2018). Top-down mechanisms reflect the influence of internal states such as intentions, expectations, or task instructions. Bottom-up mechanisms are stimulus-driven, reflecting the tendency of highly salient or novel events to capture attention, due to its physical properties, regardless of goals. Finally, experience-based mechanisms reflect the way prior learning and environmental regularities bias attentional allocation.

In practice, these mechanisms interact dynamically (Narhi-Martinez et al., 2023). While goal-relevant stimuli usually receive greater weighting, salient or novel events, and learned environmental regularities can reorient attention (Jonides & Yantis, 1988; Theeuwes, 1993, 2019), sometimes overriding ongoing priorities. This adaptive flexibility ensures sensitivity to unexpected changes, but it also means that attention can be completely redirected by stimuli that are irrelevant changing current goals (Dube et al., 2022).

This phenomenon is formalized in the concept of attentional capture, which refers to the involuntary orienting of attention toward salient stimuli even when they are irrelevant to the observer's current task. The nature of attentional capture has long been debated (Luck et al., 2021). Early stimulus-driven accounts argued that certain physically salient events—abrupt onsets, unique colors, sudden motion—automatically orient attention independent of voluntary control (Jonides & Yantis, 1988; Theeuwes, 1993). In contrast, contingent-capture theories proposed that capture occurs only when the salient stimulus matches the observer's current attentional set (Bacon & Egeth, 1994; Folk et al., 1992). More recent hybrid perspectives suggest that both mechanisms may operate in parallel (Gaspelin & Luck, 2018b; Luck et al., 2021; Ruz & Lupiáñez, 2002): salience provides a baseline tendency toward capture, but this tendency can be modulated by top-down priorities through an inhibitory mechanism (e.g., Gaspelin & Luck, 2019).

Beyond the conditions that trigger attentional shifts, researchers have also examined the unit of selection, whether attention is allocated to spatial locations or to particular features of stimuli (Carrasco, 2011; Moore & Zirnsak, 2017). Spatial attention refers to prioritizing sensory and cognitive resources for stimuli in a specific region of the visual field. This can be achieved overtly, through eye movements (e.g., Chica et al., 2010; for a review see, Zhao et al., 2012), or covertly, without observable shifts in gaze (e.g., Collie et al., 2000). For example, when searching for someone in a crowd, directing attention to a specific area enhances the ability to detect and recognize them. By increasing the clarity, speed, and efficiency of processing, spatial attention facilitates faster and more accurate responses to stimuli appearing in that location (Chica & Christie, 2009; Posner, 1980).

Feature-based attention, in contrast, selectively enhances the processing of items that share a target attribute, such as a specific color, shape, or motion, regardless of where they are located (Bichot et al., 2015; Moore & Zirnsak, 2017). For instance, when looking for someone with a distinctive characteristic (e.g., red hair) in that same crowd, attention boosts your sensitivity to red features across the entire visual fields. Thus, spatial and feature-based attention provide complementary mechanisms: one constrains processing to a location, the other to a defining property.

While these processes primarily describe the allocation of external attention, attention is not confined to perceptual inputs from the environment; it can also be directed toward internally generated representations (Chun et al., 2011; Narhi-Martinez et al., 2023). Internal attention operates over information generated within the mind, rather than derived from immediate sensory input. It encompasses the selection and prioritization of internal representations, whether held in working memory or retrieved from long-term memory (Chun et al., 2011), as well as non-sensory constructs such as motor plans, task rules, and future goals (Ede & Nobre, 2023; Luck & Vogel, 1997). Like external attention, it can be conceptualized as a competitive weighting process, prioritizing goal-relevant representations while down-weighting less relevant ones (Chun et al., 2011).

Crucially, internal and external attention interact dynamically rather than operating in complete isolation (Narhi-Martinez et al., 2023; Verschooren et al., 2019). Externally attended information is more likely to be encoded into memory (Dube et al., 2017; Dudukovic & Wagner, 2006; Turk-Browne et al., 2013), while strongly weighted internal representations can bias perception toward matching features in the environment (Olivers, 2008). This dynamic enables internal attention to reprioritize information as the external situation changes (Oberauer, 2002; van Moorselaar et al., 2015), ensuring that the most relevant internal representation exerts the strongest influence on behavior. For example, when searching for a friend in a crowd, one may retrieve a mental representation of a distinctive feature, and use it to guide perception, selectively matching that feature against the visual scene.

Yet this interaction does not imply flawless coordination. Switching between internal and external attention is not cost-free. Behavioral studies demonstrate switch costs, observed as delays and reduced effectiveness in processing information when attention alternates between the two domains (Gilbert et al., 2005; Verschooren et al., 2019). Importantly, these costs are asymmetric: reallocating attention from external perceptual input to internal representations is more demanding than the reverse (Verschooren et al., 2019, 2020).

The complex interplay between external and internal, spatial and feature-based and automatic and goal-directed process cannot be managed solely by bottom-up

salience or local competition. A higher-level control system is therefore assumed to arbitrate among these alternatives, ensuring that attention remains consistent with individuals' goals (Chun et al., 2011; Funes & Lupiáñez, 2003; Meyyappan et al., 2025; Noudoost et al., 2010; Posner & DiGirolamo, 1998). This system, known as cognitive control, is considered a top-down mechanism because it configures attentional priorities in line with expectations and contextual demands rather than relying solely on stimulus salience (Chun et al., 2011; Noudoost et al., 2010).

Cognitive control is thought to operates by biasing competition between relevant and irrelevant information through two complementary processes (Bashinski & Bacharach, 1980; Gaspelin & Luck, 2019; Luck et al., 2021; Meyyappan et al., 2025; Moore & Zirnsak, 2017; Noudoost et al., 2010; Ridderinkhof, 2002b). Enhancement boosts the efficiency of processing priority-relevant inputs, while suppression or inhibition down-regulates distractors, sometimes to below baseline levels (Moore & Zirnsak, 2017; Narhi-Martinez et al., 2023). Together, these processes ensure that attentional allocation remains aligned with ongoing priorities, even in a changing environment filled with competing or distracting signals.

Functionally, cognitive control can be understood as a supervisory attentional gateway (Burgess et al., 2007; Verschooren et al., 2019): a system that selectively amplifies one domain, such as internal or external attention, while suppressing the other, thereby maintaining coherence in behavior. Crucially, this control can operate in different modes. It may function proactively, by configuring attentional sets in advance of expected demands and sustaining goal-relevant representations over time, or reactively, by being recruited transiently to resolve interference once a competing event has occurred (Braver, 2012; Mäki-Marttunen et al., 2019). These modes seem to be partially independent processes that can be flexibly combined depending on situational demands (Mäki-Marttunen et al., 2019; Torres-Quesada et al., 2022). For example, during a lively conversation in a noisy café, proactive control biases perception toward the speaker's voice, while reactive control intervenes if a sudden crash or shout momentarily disrupts focus.

In this sense, cognitive control should not be seen merely as a selector of inputs but as a regulator of competition, dynamically shaping the priority map that governs

which representations gain access to downstream processing and action (Chun et al., 2011; Meyyappan et al., 2025; Noudoost et al., 2010). Although this regulatory flexibility supports adaptive behavior, it also explains why rapid reconfiguration is effortful: suppressing one domain while amplifying another imposes time and resource costs that manifest as switch costs, slower processing speed, and reduced accuracy.

Building on this theoretical foundation, it becomes essential to ask how these attentional principles can be observed and quantified in practice. Cognitive psychology has approached this challenge by developing experimental paradigms that translate constructs such as competitive weighting, cognitive control, and the balance between internal and external priorities into measurable behavioral effects (Cañadas & Lupiáñez, 2012; Chica et al., 2014; Lu & Proctor, 1995; Lupiáñez & Funes, 2005; Marotta et al., 2012; Posner, 1980).

These paradigms typically manipulate stimulus characteristics, such as type, timing, and validity, to examine how attention is deployed across space or toward particular features (e.g., Chica et al., 2010). In addition, they often introduce conflicts between relevant and irrelevant inputs, allowing researchers to assess how control processes resolve interference (e.g., Fan et al., 2018). By comparing performance under these different conditions, researchers can trace the dynamics of attentional shifts and control mechanisms and their consequences for cognitive processes, such as perception, memory, decision-making and, of main importance for this thesis, social cognition.

Classic paradigms have therefore provided not only the foundation for understanding general mechanisms of attention but also a framework for extending these questions into social domains (Cañadas & Lupiáñez, 2012; Chacón-Candia, Román-Caballero, et al., 2023; Marotta et al., 2012, 2018), where stimuli such as gaze direction or facial expressions act as cues that guide or interfere with attentional allocation.

Among these, in the following section we will review two classes of paradigms that have been particularly influential in the study of attention, and are more relevant for this doctoral thesis: the spatial orienting paradigm (Chica et al., 2014; Posner, 1980), and the spatial interference paradigm (Lu & Proctor, 1995). These provide complementary perspectives on attentional mechanisms. Orienting paradigms examine how attention is

deployed across space, whereas interference paradigms reveal how control process resolve conflicts between competing sources of information.

1.2. Experimental Paradigms for Studying Visual Attention

1.2.1. The Spatial Orienting Paradigm

Given their central role in shaping the study of attention, it is useful to begin by examining the spatial orienting paradigm (Chica et al., 2014; Posner, 1980), one of the most influential tools in cognitive psychology and cognitive neuroscience. This paradigm has been pivotal for understanding how attention is allocated across the visual field and how shifts of attention affect or are affected by other stages of processing.

In its classic form, participants maintain fixation at the center of the screen while, either centrally or peripherally, a cue is presented providing information about the location of an upcoming target to which they must respond. The cue may be valid, correctly indicating the target location; invalid, directing attention to a different location; or neutral, providing no spatial information (Chica et al., 2014). Performance is then compared across cue conditions, typically in terms of reaction times (RTs) and accuracy. Faster and more accurate responses on valid (cued) trials are taken as evidence of attentional benefits, while slower and more error-prone responses on invalid (uncued) trials index the costs of misdirected attention. The difference between valid and invalid trials is known as the cueing effect.

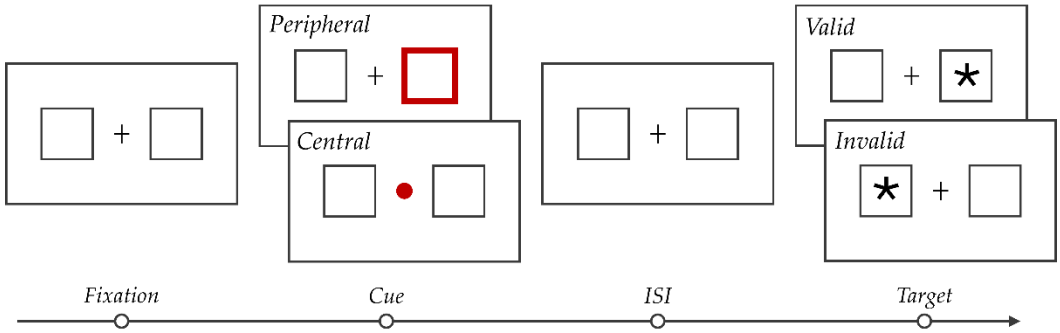
As outlined in the previous section, spatial orienting can be driven by two distinct modes of allocation, known in this experimental context as endogenous (voluntary, top-down) and exogenous (involuntary, bottom-up) attention (Carrasco, 2011; Chica et al., 2014; Dugué et al., 2020). Endogenous orienting is guided by internal goals and expectations, for example when participants are instructed to attend to the left because most targets will appear there. Exogenous orienting, by contrast, is triggered reflexively by salient events in the environment, such as sudden onsets or flashes, which capture attention automatically. The distinction closely parallels the weighting principles described earlier (Narhi-Martinez et al., 2023): endogenous orienting reflects the prioritization of internal control settings over competing input, while exogenous orienting reflects the system's sensitivity to unexpected but potentially relevant changes in the external environment.

The type of cue used plays a critical role in differentiating these mechanisms. Peripheral cues, such as abrupt luminance changes or sudden onsets near the target

location, reliably produce exogenous shifts of attention even when they are spatially uninformative (i.e., non-predicting the target location). By contrast, central or symbolic cues, such as colored shapes, arrows, numbers, or words, require interpretation before attention can be shifted (Carrasco, 2011; Chica et al., 2014). Symbolic cues are therefore commonly used to study endogenous orienting, as their influence depends on the participant's ability to process, maintain, and apply the meaning of the cue. Both types of experimental manipulations are illustrated in **Figure 1**.

Figure 1

Example of a Trial Sequence in the Spatial Orienting Paradigm



Note. Example of a trial sequence in the spatial orienting paradigm (adapted from Chica et al., 2014). Participants first fixate on a central cross flanked by two placeholders. A cue is then presented either peripherally (e.g., a luminance or color change in one placeholder) or centrally (e.g., a symbolic cue such as a colored dot; for instance, red indicates that the target will most likely appear in the right placeholder). After a variable cue–target interval (ISI), the target appears in one of the placeholders, either validly or invalidly cued.

It has been observed that symbolic cues orient attention only if they are predictive of target location (e.g., ~75% valid; Funes et al., 2007). Interestingly, however, overlearned cues such as arrows or directional words can cue attention even when they are non-predictive of target location (Hommel et al., 2001; Ristic et al., 2002; Ristic & Kingstone, 2012). Thus, although symbolic cues are usually voluntary, arrows and words can also elicit automatic orienting, resembling reflexive attention.

From a theoretical perspective, the spatial orienting paradigm has been instrumental in demonstrating that attentional orienting is not a unitary phenomenon but rather reflects the interplay between automatic and controlled processes**.** Symbolic cues like arrows, in particular, illustrate how attentional allocation can extend beyond

reflexive shifts in perceptual focus to engage internal mechanisms that might be shaped not only by current task-goals, but also by their inherent symbolic and communicative meaning (Hommel et al., 2001; Uncapher et al., 2011).

This becomes especially relevant when the symbolic cue carries social meaning, as with gaze direction (Bayliss et al., 2006; Dalmaso et al., 2020), which reliably elicits a cueing effect (Brignani et al., 2009; Friesen & Kingstone, 1998). Although in the classic Posner paradigm gaze and other types of cues, such as arrows, appear to produce similar orienting effects (for a review see, Chacón-Candia, Román-Caballero, et al., 2023), later adaptations have revealed important differences, suggesting that gaze might engage additional processes during orienting attention (Chacón-Candia, Lupiáñez, et al., 2023; Marotta et al., 2012). The classic paradigm nevertheless provided the starting point for the conceptual and methodological study of social attention.

1.2.2. The Spatial Interference Paradigm

Whereas orienting paradigms measure the deployment of attention across space, spatial interference paradigms examine how control mechanisms resolve competition when spatial information provides conflicting signals. In the Spatial Interference paradigm, a spatially biased stimulus (e.g., an arrow pointing left or right) is presented either to the left or to the right, and participants must respond to its direction, i.e., a task-relevant feature, while ignoring the irrelevant spatial position of the stimulus. The defining feature of these paradigms is that the target stimulus simultaneously serves as both the target and the source of interference. The generated conflict requires the control system to regulate competition at different processing stages (Lu & Proctor, 1995; Viviani, Visalli, Montefinese, et al., 2024). The two most widely studied paradigms are the Simon and the spatial Stroop task, both of which demonstrate that location information influences performance even when it is irrelevant to the task.

A broader theoretical approach has been developed to study conflict tasks, including the Simon and the spatial Stroop, based on the notion that different processes act simultaneously on the stimulus input, namely the dual-route framework (Cohen et al., 1990; Hommel, 1993; Ridderinkhof, 2002b; Ulrich et al., 2015). According to this model, two mechanisms operate in parallel: a fast, automatic route triggering responses based on irrelevant features, and a slower, controlled route that process task-relevant

responses. Conflict arises from the interaction between these routes. This perspective provides a useful framework to quantify and study control mechanisms, potentially pointing to structural and functional differences between the two tasks.

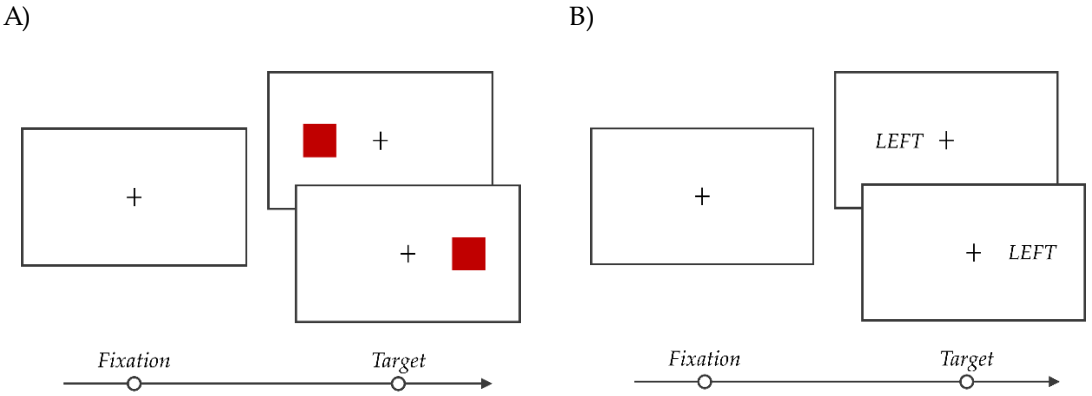
In the Simon task (Simon, 1969), participants respond to a non-spatial feature of a stimulus (e.g., its color or shape) with left- or right-hand keypresses, while the stimulus itself is displayed randomly on the left or right side of the screen. Although location is irrelevant, responses are faster and more accurate when the stimulus appears on the same side as the required response (compatible trials) than when it appears on the opposite side (incompatible trials). This Simon effect is thought to reflect the automatic activation of a response code by irrelevant spatial information (De Jong et al., 1994; Ulrich et al., 2015). Even with extended practice, the effect persists, suggesting that it reflects a fundamental property of human information processing rather than a superficial strategy (D'Ascenzo et al., 2021).

The spatial Stroop task introduces conflict differently. Here, the task-relevant feature itself conveys spatial meaning, for example, an arrow pointing left or right, or the words "*LEFT*" or "*RIGHT*". These stimuli can appear in locations that are spatially congruent or incongruent with their meaning, and participants must indicate the symbolic direction with a left or right keypress. For instance, judging that an arrow points left is faster and more accurate when it appears on the left side (congruent trial) than when it appears on the right (incongruent trial). As in the Simon task, stimulus location is irrelevant, but here it competes with the intrinsic symbolic meaning of the stimulus (Lu & Proctor, 1995; Viviani, Visalli, Montefinese, et al., 2024).

Thus, although the Simon and spatial Stroop tasks arise from different traditions, stimulus–response compatibility in the former and Stroop-like interference in the latter (Stroop, 1935), both illustrate the obligatory processing of irrelevant spatial information. **Figure 2** shows typical sequences for each task.

Figure 2

Typical sequences of the Simon and Spatial Stroop Task



Note. Typical trial sequences. (A) Simon task: Participants first fixate on a central cross. A target then appears to the left or right of fixation, and responses are made based on a non-spatial feature such as form or color (e.g., red = right-hand response, blue = left-hand response). A red square on the left constitutes a congruent trial, whereas a red square on the right constitutes an incongruent trial. (B) Spatial Stroop task: As in the Simon task, participants fixate centrally. The target then appears, but here responses are based on the symbolic or literal meaning of the stimulus. In the example, participants respond to the meaning of the word: the word *LEFT* presented on the left is congruent, while *LEFT* on the right is incongruent.

A central question regarding these conflict effects has been why irrelevant spatial information influences performance. In the case of Simon effect, early accounts suggested that the onset of a stimulus automatically biases attention toward its location, facilitating the corresponding response (Lu & Proctor, 1995). However, subsequent evidence has shown that the Simon effect persists even when stimulus and response locations are both on the same side of the midline (Umilta & Nicoletti, 1985; Weeks et al., 1996), challenging a pure orienting explanation.

More widely accepted are spatial coding accounts (Cespón et al., 2020; Van der Lubbe et al., 2005), which argue that both the stimuli and response are automatically coded in spatial terms. Interference arises when these codes mismatch: overlap between irrelevant stimulus location and response location activates a competing response, leading to facilitation when codes match and conflict when they do not (De Jong et al., 1994; Kornblum, 1992; Umiltá & Nicoletti, 1990). From this perspective, the Simon effect

exemplifies stimulus-response (S-R) conflict (Cespón et al., 2020). Interestingly, attention shifts might play a role in spatial coding still (Melara et al., 2008; Rubichi et al., 1997).

By contrast, the spatial Stroop effect appears to rely on partly different mechanisms (Li et al., 2014; Torres-Quesada et al., 2022), involving a more complex interplay. Interference arises not only from mismatches between stimulus and response codes, as in the Simon task, but also from stimulus-stimulus (S-S) conflict, where the symbolic meaning of the target competes with its location. This layered overlap means that Stroop interference can occur at multiple levels—stimulus, response, and task—making it a richer case of dimensional overlap (Viviani, Visalli, Montefinese, et al., 2024).

Among these paradigms, the spatial Stroop task is especially relevant for the present thesis. Positioning it within the broader family of spatial interference paradigms clarifies how it operates and highlights its distinctive overlapping dimensions compared with the Simon task.

In this regard, the Stroop task can be adapted to incorporate symbolic or socially meaningful cues, such as gaze direction, thereby enabling the study of social influences within a well-established interference framework. This adaptability, when situated within the dual-route framework, makes it particularly valuable for distinguishing task-related sources of conflict from those specifically tied to social signals. Previous studies have successfully employed such variants to investigate how social cues shape attentional orienting and control (Cañadas & Lupiáñez, 2012; Marotta et al., 2018).

Both the orienting and the interference paradigms have been instrumental in advancing our understanding of attention in general and social attention in particular. This dual contribution provides the basis for the next section, which turns specifically to the role of gaze in social attention.

1.3. Gaze and Social Attention

1.3.1. Gaze as a Social Signal

Social attention refers to the set of processes by which humans detect, interpret, and respond to socially relevant signals in their environment. It involves both attentional engagement with social-related stimuli themselves (e.g., attending to faces or bodies) and orienting toward objects or locations indicated by others' signals, such as gaze, or head orientation (Capozzi & Kingstone, 2024; Capozzi & Ristic, 2018). Together, these components provide the foundation for understanding how individuals coordinate in interaction.

Among such signals, nonverbal cues—including gaze, facial expressions, gestures, and body posture—play a central role. They naturally guide perception and attention (Capozzi & Kingstone, 2024; Yang et al., 2015), often engaging observers automatically even when irrelevant to current goals (Bindemann et al., 2005; Rösler et al., 2017; Stein et al., 2012). This prioritization is thought to reflect evolutionary pressures, highlighting the importance of social signals for survival, communication, and group coordination (Capozzi & Ristic, 2018; Stephenson et al., 2021).

Faces are among the most information-rich visual stimuli humans encounter, providing cues about identity, emotion, intentions, age, and social traits (Oruc et al., 2019). Research shows that face perception relies on specialized mechanisms such us holistic and configural, rather than purely feature-based, processing strategies (Itier & Preston, 2018; Maurer et al., 2002). Configural processing refers to the analysis of spatial relationships between facial features, whereas holistic processing integrates both featural and configural information into a unified percept (Miki et al., 2015; J. W. Tanaka & Farah, 1993; J. W. Tanaka & Gordon, 2011). These processes are supported by dedicated cortical regions such as the fusiform face area. Developmentally, humans display a preference for face-like and face stimuli from the earliest stages of life, and face recognition abilities continue to refine throughout childhood (Cashon & Holt, 2015; Hadders-Algra, 2022), making us experts in face processing (Gauthier & Nelson, 2001).

Within faces, the eyes are especially informative. They engage rapid perceptual processing (Itier et al., 2007; Nemrodov et al., 2014), serve as anchors in holistic strategies (Itier & Preston, 2018), and are preferentially fixated in non-speaking faces (Vinette et al.,

2004). They are also particularly relevant for recognizing emotional expressions. As communicative signals, comparative studies show that humans look more to eyes than less social primates, reflecting their role in advanced communication (Kano et al., 2015, 2018). These findings highlight the privileged status of the eyes in face perception, central for interpreting expressions and communication

Beyond their role as a static feature in face processing, the human eye itself has evolved features that directly engage attentional systems, enhancing its communicative value through gaze shifting. Morphologically, our species is unique in displaying a horizontally elongated sclera with high luminance contrast against the iris, which makes gaze direction highly visible (Kobayashi & Kohshima, 1997, 2001). Comparative evidence suggests that this morphology evolved to improve gaze signaling, thereby facilitating cooperation and coordination (Emery, 2000; Tomasello et al., 2007).

Functionally, gaze exert three main attentional effects (Dalmaso et al., 2020). Attention holding, which refers to the difficulty of disengaging from direct gaze compared to averted or closed eyes (Hietanen et al., 2016; Syrjämäki & Hietanen, 2020). Attention capture describes the tendency for direct gaze to attract attention more rapidly than averted gaze (Böckler et al., 2014; Senju et al., 2005). Attention shifting occurs when averted gaze directs attention toward external objects or locations (Jording et al., 2018).

Among these effects, attention shifting is especially relevant, as it underlies how gaze direction can trigger the orienting of attention (Dalmaso et al., 2020). When someone shifts their gaze toward a location, observers often align their own attention with that direction, often automatically (Ulloa et al., 2018). This orienting response ensures rapid allocation of attention to potentially relevant parts of the environment. In addition, unlike arbitrary directional cues, gaze is thought to carry intrinsic social meaning, signaling another's focus of interest and potential intentions (Stephenson et al., 2021).

In this view, orienting triggered by gaze shifts shows properties of both reflexive (exogenous) and voluntary (endogenous) attention. On the one hand, gaze can orient attention rapidly and automatically independently of the current goals (Friesen & Kingstone, 1998), similar to a sudden peripheral onset. On the other, gaze effects are modulated by context, expectations, and task demands, reflecting top-down influences

(Dalmaso et al., 2020). This duality highlights the flexibility of gaze as both a rapid orienting cue and a communicative signal (Murray et al., 2023).

From a developmental perspective, gaze following is the first key step linking gaze perception to social learning. From the first months of life, infants not only prefer looking at the eyes but also begin to follow others' gaze (Del Bianco et al., 2019). Through this mechanism, they gain access to aspects of the environment highlighted by others, providing opportunities for learning about objects, events, and intentions. This early ability is considered a foundational mechanism because it supports the emergence of higher-order socio-cognitive processes (Stephenson et al., 2021).

Two key processes that build on gaze following are joint attention and shared attention (sometimes used interchangeably but conceptually distinct, Stephenson et al., 2021). Joint attention refers to the capacity of two individuals to coordinate their focus on the same object or event (Capozzi & Kingstone, 2024). By stablishing a shared reference point, joint attention facilitates cooperative behaviors (Mundy, 2018). Shared attention, by contrast, adds a further layer: both partners are not only attending to the same object but are also mutually aware of this fact (Stephenson et al., 2021). This reciprocal awareness transforms joint focus into an experience of mutual understanding. Shared attention is therefore considered a building block for empathy, bonding, and theory of mind.

In sum, gaze functions as both a perceptual focus and a communicative signal that shapes visual attention. It engages mechanisms of perception, orienting, and interpretation, linking basic attentional operations with advanced socio-cognitive processes. At the same time, gaze illustrates how attention is not only captured by external signals but also dynamically controlled in relation to internal representations (**Section 1.1.**).

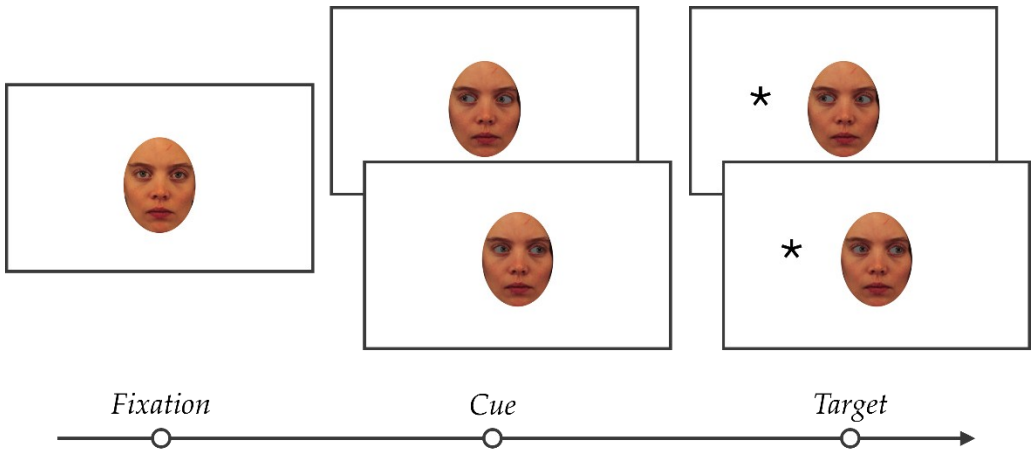
This centrality of gaze in social attention has motivated extensive experimental research. The most influential approach is the gaze-cueing paradigm, which captures gaze-driven orienting under controlled laboratory conditions. This paradigm, and the debates it has generated about whether gaze effects are special or domain-general, will be the focus of the next section.

1.3.2. The Gaze-Cueing Paradigm

The central role of gaze in attentional orienting has been operationalized experimentally through the gaze-cueing paradigm (Friesen & Kingstone, 1998), a direct adaptation of Posner's (1980) spatial cueing task (see **Section 1.2.1.**). In its classic form, participants fixate on a central face stimulus that initially looks straight ahead. The face then shifts its gaze leftward or rightward, followed by the presentation of a peripheral target either at the gazed-at location (valid trials) or at the opposite location (invalid trials). Participants are instructed to detect, localize, or discriminate the target as quickly and accurately as possible. **Figure 3** depicts a typical trial sequence of a gaze-cueing task.

Figure 3

Typical Trial Sequence of the Gaze-Cueing Task



Note. Typical gaze-cueing trial sequence. First, a central fixation cross appears, and participants are instructed to focus on it. Next, a centrally presented face looking straight ahead is displayed, followed by the cue: the same face gazing either left or right. Finally, a target appears on the left or right. If the target appears at the gazed-at location (e.g., the face looks left and the target appears on the left), the trial is considered valid; otherwise, it is invalid.

The robust finding is that responses are faster and more accurate on valid than invalid trials, even when gaze direction is non-predictive of target location, indicating that gaze exerts an automatic influence on attentional orienting (Brignani et al., 2009; Driver et al., 1999; Friesen & Kingstone, 1998; Ulloa et al., 2018). This result was notable because central, symbolic cues are typically thought to require predictive validity to elicit cueing effects (Chica et al., 2014). Yet, as discussed in **Section 1.2.1.**, arrows can also

produce automatic shifts of attention under non-predictive conditions (Hommel et al., 2001; Ristic et al., 2002), suggesting that automatic orienting may not be unique to gaze.

Because gaze plays such a central role in social cognition, as noted in the previous section, researchers turned to direct comparisons with arrows to assess whether the two cues rely on different forms of automaticity (Dalmaso et al., 2020). Under this assumption, the automatic processing of arrows may reflect overlearned associations with symbolic meaning (Hommel et al., 2001), while gaze processing appears more strongly rooted in social and biological predispositions (Yang et al., 2015), consistent with evidence of early-emerging gaze-following abilities in infants. From this perspective, gaze and arrows may share some general orienting mechanisms but also diverge in the extent to which their effects are tied to social predisposition versus non-social processes.

To examine this possibility, researchers have varied key aspects of the cueing paradigm (Chacón-Candia, Román-Caballero, et al., 2023). Manipulations included the type of task (detection, discrimination, or localization), the predictive value of the cue (non-predictive, predictive, or counter-predictive), the format of the stimuli (schematic vs. realistic), and temporal factors such as cue duration and stimulus onset asynchrony (SOA; the interval between cue presentation and target onset).

However, a large-scale meta-analysis showed that the magnitude of cueing effects is statistically equivalent for gaze and arrow cues across a wide range of task designs (Chacón-Candia, Román-Caballero, et al., 2023). Both yielded comparable facilitation regardless of whether the task involved detection, discrimination, or localization, and whether cues were predictive, counter predictive, schematic, or realistic. Comparable patterns also emerged across participant populations and experimental settings.

At the same time, a few studies suggest that differences between gaze and arrows may emerge when the paradigm is combined with additional manipulations aiming at looking for qualitative rather than quantitative differences. For example, studies of object-based attention show that arrows tend to spread attention across entire cued objects, whereas gaze restricts attention more narrowly to the specific gazed-at region (Chacón-Candia et al., 2020; Chacón-Candia, Lupiáñez, et al., 2023; Marotta et al., 2012). Similarly, when gaze cueing is paired with working memory tasks, gazed-at items are more robustly encoded than arrow-cued items (Gregory & Jackson, 2017, 2019). Other

extensions suggest that gaze, but not arrows, can modulate affective evaluation (Bayliss et al., 2006) or influence long-term memory encoding (Dodd et al., 2012). Although limited in number, these studies indicate that gaze may recruit additional processes related to mentalizing, intention attribution, and social relevance—processes not typically engaged by arrows.

These observations point to an important limitation of the classic cueing paradigm: it may underestimate differences between gaze and arrows (Chacón-Candia, Román-Caballero et al., 2023). A likely reason is that the two cues are usually compared in terms of their shared directional function (Birmingham & Kingstone, 2009; Gibson & Kingstone, 2006), a dimension in which they are highly similar.

By contrast, paradigms that treat gaze and arrows as targets, and therefore require participants to process the symbolic meaning of gaze through its directional information, might offer a more sensitive test of potential differences. Indeed, evidence from spatial interference tasks has shown that gaze stimuli can produce distinctive patterns not observed with arrows (Cañadas & Lupiáñez, 2012; Marotta et al., 2018). For this reason, researchers have increasingly turned to interference paradigms, which allow gaze and arrows to be compared not only as directional cues but also as targets whose symbolic meaning might directly engages control mechanisms.

1.4. The Spatial Interference Paradigm in Social Attention Research

1.4.1. From Gaze Cueing to Spatial Interference

The transition from classic gaze-cueing to the spatial interference paradigms did not arise from a gaze-arrow debate, but from the need to examine more directly how gaze direction interacts with other signals (Cañadas & Lupiáñez, 2012). As discussed in the previous section, humans detect gaze shifts through mechanisms that reflect a complex interplay between low-level and higher-order systems. During this integration, gaze direction is rarely processed in isolation but in conjunction with head and body orientation (Langton & Bruce, 2000; Yang et al., 2015). This integration makes gaze highly informative, yet it also opens the door to conflict when cues point in different directions, for example, when gaze is directed to the right while the head is oriented to the left.

Research on the interaction between gaze direction and head orientation has yielded inconsistent results. In some studies, gaze direction interfered with judgments of head orientation, while in others, judgments of gaze direction were facilitated when head and gaze were inconsistent (cf., Langton, 2000; Ricciardelli et al., 2000; Ricciardelli & Driver, 2008). Cañadas & Lupiáñez (2012) argued that these contradictions might stem from the fact that eye contact was not explicitly controlled in these designs. When head and gaze are misaligned, the eyes may still fall on the observer's central fixation, creating the subjective impression of being looked at. This sensitivity to direct gaze could explain why performance sometimes improves under apparently conflicting conditions.

To test this idea, Cañadas & Lupiáñez (2012) adapted the spatial Stroop task using social stimuli as targets. Instead of manipulating head orientation, they manipulated the spatial location of the face itself, presenting it to the left or right of fixation while participants judged gaze direction. This created congruent conditions, where gaze and face location aligned, and incongruent conditions, where gaze pointed opposite to the face's position (e.g., a left looking face presented to the right of the fixation point). Crucially, on incongruent trials, the gaze aligned with the observer's fixation, putatively eliciting the impression of eye contact. Thus, incongruent conditions were hypothesized to facilitate responses due to the special salience of direct gaze (**Section 1.3.1.**), inverting the standard Stroop pattern.

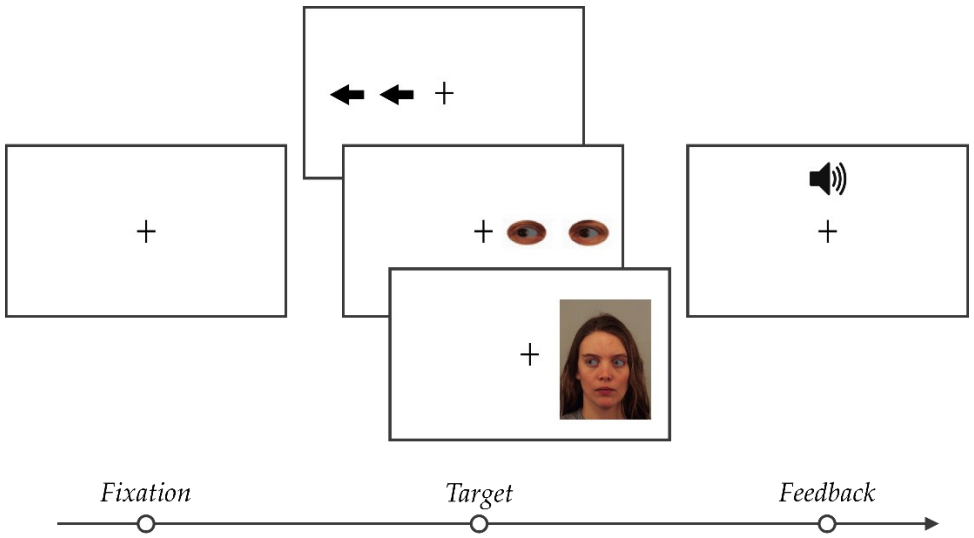
Their results confirmed this prediction. When participants judged gaze direction in faces (Experiment 1) and isolated eyes (Experiment 2), they consistently showed a reversed congruency effect (RCE): responses were faster on incongruent trials, when gaze was directed toward fixation, than on congruent trials, when gaze was averted. By contrast, when non-social control stimuli were used (triangles or symbolic "eyes"; Experiment 3), the standard congruency effect (SCE) reappeared, with faster responses on congruent than incongruent trials. These results were taken as evidence that the reversal was specific to socially meaningful stimuli and likely driven by the special salience of direct gaze.

Subsequent studies replicated the RCE and showed its sensitivity to contextual and individual factors, such as emotional expression (Jones, 2015) and personality traits (Torres-Marín et al., 2017). These replications not only established the robustness of the effect but also position the spatial Stroop as a valuable tool for studying gaze-related interference.

A further step was to place gaze and arrows within the same task to examine their effects in a common context. Although both stimuli produce comparable cueing effects in orienting paradigms (**Section 1.3.2.**), their interference patterns had typically been studied separately. Marotta and colleagues (2018) addressed this by presenting both stimulus types in the same experimental design. As expected, arrows elicited the SCE, with faster responses on congruent trials, whereas gaze produced the RCE. **Figure 4** represents a typical sequence in the spatial Stroop.

Figure 4

Typical Trial Sequence of the Spatial Stroop Task



Note. The figure shows a typical trial sequence of the spatial Stroop task. Each trial begins with a central fixation that participants are required to focus. A target then appears to the left or right of fixation, in this example, arrows (non-social targets) in congruent trials, and isolated eyes or faces (social targets) in incongruent trials. Participants respond by pressing the left key if the target points or looks left, and the right key if it points or looks right. An error signal (a brief sound) is given after incorrect responses.

Together, these findings confirmed the RCE as a distinctive phenomenon in the spatial Stroop with gaze stimuli. The contrast with arrows showed that gaze does not simply act as another directional cue but engages additional mechanisms that alter interference dynamics. What those mechanisms are—whether social, perceptual, or task-related—remains an open question. Addressing this complexity requires moving beyond the initial demonstrations to examine the factors that determine when and how the RCE emerges, and whether it can also be observed with non-gaze targets, a task taken up in the following sections.

1.4.2. The Reversed Congruency Effect: Characteristics and Modulators

Since its first demonstration by Cañadas and Lupiáñez (2012), the RCE has become a central phenomenon in the study of social attention. Replications and extensions have confirmed its robustness, while also showing that its magnitude, and even its direction, are highly sensitive to multiple factors.

The sources of this variability have been examined from several perspectives, which can be grouped into four categories: (a) task-related factors, (b) social and stimulus-specific modulations, (c) individual and developmental differences, and (d) dynamic and neural evidence.

Target Types & Task-Related factors

A first task-related determinant of the RCE is the type of target used to compare the resultant effects. Classic comparisons show that arrows consistently elicit the SCE, while gaze produces the RCE (Marotta et al., 2018). This contrast has been replicated across several studies, confirming a robust dissociation between these two targets (Chacón-Candia et al., 2024; Dalmaso et al., 2023; Ishikawa et al., 2021; Marotta et al., 2019; Narganes-Pineda, Chica, et al., 2023).

Other directional cues resemble arrows in producing the SCE. Pointing hands (Bonventre & Marotta, 2023; Dalmaso et al., 2023), directional words (Hemmerich et al., 2022, Experiment 3), and head orientation (Y. Tanaka & Okubo, 2024) all yielded faster responses on congruent than incongruent trials, while gaze continued to elicited the reversed pattern. These outcomes were consistent whether the different target types were presented in blocked (Bonventre & Marotta, 2023, Experiment 1; Dalmaso et al., 2023; Marotta et al., 2018), or intermixed formats (Bonventre & Marotta, 2023, Experiment 2; Hemmerich et al., 2022).

Beyond typical directional stimuli, less conventional cues have also been tested. Tongue stimuli, though unusual as attentional signal, reliably elicited the RCE (Y. Tanaka et al., 2024). By contrast, fish stimuli, which convey directional information through head direction, produced the SCE (Y. Tanaka et al., 2025).

Another approach compared arrows and gaze under conditions of matched perceptual complexity. In the initial studies, arrows were usually shown in isolation, whereas gaze was embedded in a face. Román-Caballero et al. (2021a) embedded arrows in mosaic backgrounds derived from faces to approximate the visual complexity of gaze-in-face conditions. Gaze continued to elicit the RCE, while arrows produced variable outcomes: a small reversal in one experiment and a reliable SCE when arrows were surrounded by sclera-like contours within the same complex background. Extending this line, , embedded arrows, tongues, and fish in complex backgrounds. Only tongues

yielded a robust RCE, while arrows and fish showed no spatial interference at the mean level analysis.

Similarly, Z. Chen et al. (2022) also compared stimuli under equivalent perceptual complexity. In their first experiment, they replicated the typical dissociation between gaze and arrows using Marotta et al.'s (2018) stimuli. In the second, they design infinity symbols with low perceivability, assuming they matched the visibility of gaze; both eyes and infinity symbols elicited similar congruency effects, with faster responses on incongruent trials. Finally, in their third experiment, using high-perceivability stimuli (cartoon eyes, arrows, and symbols), all three produced the SCE.

Changing the focus of the task-relevant information, thereby altering the typical overlap of sources in the spatial Stroop, also influenced the expression of congruency effects. When participants judged the colour of the stimuli, making both location and direction irrelevant (implicit task), no congruency effects were observed for either arrows or gaze. Conversely in the explicit task (standard design), the typical SCE was observed for arrows, and the RCE for gaze (Narganes-Pineda et al., 2023, Experiments 1 & 2). Furthermore, these patterns, between implicit and explicit tasks, were consistent when the response dimension was either manual or verbal (Narganes-Pineda et al., 2023, Experiment 3).

A further study compared two groups: one judged stimulus direction (as in standard designs), while the other judged the colour toward which the stimulus was directed (Aranda-Martín et al., 2023). In this latter condition, colors were fixed to preserve the same response-mapping aligned with stimulus direction, altering only the participants' focus on the type of task-relevant information. The results showed no differences between groups, indicating that the manipulation did not affect either the typical dissociation between gaze and arrows or the magnitude of the RCE.

In another study, fixation context was manipulated to examine modulations of gaze-related interference (Edwards et al., 2020). Participants judged the direction of gaze of peripheral faces while fixating either a central or peripheral fixation. In Experiment 1, facilitation for inward gaze was observed with central fixation (equivalent to incongruent trials in the standard design), whereas no interference emerged with peripheral fixation. In Experiment 2, fixation crosses were replaced with real-world objects. Here, responses

were faster when gaze was directed toward the fixation target, producing an RCE under central fixation but a standard effect when fixation was peripheral. This manipulation further showed that the RCE is sensitive to visual eccentricity, although gaze was not compared with a non-social control stimulus.

Finally, studies outside the immediate RCE literature further highlight the impact of task-related factors. Fan et al. (2018) used cartoon eyes and arrows in a four-location spatial compatibility task (a mixed of Stroop-like tasks; Kornblum, 1992). Participants judged stimulus direction (left or right) with either a left-right (Experiment 2a) or up-down (Experiment 2b) response mapping, while ignoring stimulus location (up, down, left or right). Arrows showed the expected compatibility effect (i.e., faster responses when target direction was compatible with its location), but gaze stimuli were unaffected by location, even in the left–right condition that closely parallels the Stroop setting. This contrasts with Z. Chen et al. (2022), who reported an SCE with cartoon eyes, suggesting that expanding the response–location mapping can modulate gaze-related interference even with high-perceivability stimuli.

A different approach was taken by A. Chen et al. (2024), who manipulated whether background location was relevant or irrelevant in a vertical Stroop-like task. Here, direction and location were varied on the vertical axis (targets appeared above or below fixation and pointed up or down), while responses were given with a left-right mapping. The gaze stimuli were cartoon eyes. When participants judged target direction (Experiment 1), arrows produced a congruency effect, but gaze yielded a null effect. When participants explicitly judged the match between target direction and background location (Experiment 2), both arrows and gaze elicited the standard interference effect.

Social and Stimulus-Specific Modulations

Within social stimuli, the RCE has been examined in relation to face orientation, emotional expression, and face type. Upright faces were compared with inverted faces, which are assumed to disrupts holistic and/or configural processing in face recognition studies (Freire et al., 2000; Itier & Preston, 2018; Maurer et al., 2002). In this case, the magnitude of the RCE was unaffected, with both orientations producing a clear reversal (Marotta & Lupiáñez, 2018; Y. Tanaka et al., 2023).

Emotional expressions, on the other hand, did modulate the strength of the RCE. The effect was larger for happy and angry faces, reduced for fearful and absent for neutral faces (Jones, 2015). A similar pattern was reported when happy faces were compared with negative or neutral ones, with happiness producing the largest reversal (Marotta et al., 2022). In another study, the RCE was replicated across all emotional expressions, but differences in magnitude were not analyzed in detail, as the main focus was on error rates (Torres-Marín et al., 2017). More recently, the RCE was examined in relation to both emotional expression and face orientation (Y. Tanaka et al., 2023, Experiment 2). Its magnitude remained stable across emotions and was unaffected by whether the face was upright or inverted.

The RCE has also been analyzed beyond human faces. In a series of experiments, gaze stimuli from humans, cats, fish, koalas, and robots were used as targets in the spatial Stroop task (Ishikawa et al., 2025). Human and cat gazes reliably elicited the RCE, koala gaze produced a smaller but significant reversal, and fish and robot gaze failed to generate the effect.

Lastly, an important distinction within the social stimuli concerns whether gaze is presented within whole faces or as isolated eyes. Román-Caballero et al. (2021b) suggested, based on previous observations, that RCEs may be larger for faces than for cropped eyes, an idea later emphasized by Aranda Martín (2023), who argued that full faces add both complexity to directional information extraction and richness to the social signal. In line with this, Y. Tanaka & Okubo (2024, Supplementary Material) found an RCE for faces but no spatial interference for isolated eyes, suggesting that the reversal might be more stable when gaze is embedded in a full-face context.

Individual and Developmental Differences

The RCE has also been examined in relation to stable individual traits and development, showing that socio-emotional and age profiles can modulate its expression. For example, individuals high in gelotophobia (fear of being laughed at) were less accurate in judging gaze, particularly when gaze incongruent trials (Torres-Marín et al., 2017). Similarly, when comparing individuals with high versus low autistic traits, both groups showed the RCE, but the larger reversal observed with happy expressions was not observed in the high-trait group (Marotta et al., 2022).

Social anxiety has also been linked to differences in gaze-related interference. Higher levels of social anxiety were associated with a reduced RCE, while the SCE for arrows and words remained unaffected (Ishikawa et al., 2021). Other research has examined ADHD traits. In a non-clinical adult sample, the dissociation between gaze and arrows was replicated, but ADHD-like traits did not modulate the magnitude of either effect (Chacón-Candia et al., 2024).

From a developmental perspective, the RCE appears later than the SCE. In a large sample of children and adolescents, arrows reliably elicited the SCE at all ages, whereas gaze showed a different trajectory: an SCE at age 4, no effect between ages 5 and 10, and a significant RCE emerging by age 12 and consolidating during adolescence (Aranda-Martín et al., 2022). These findings suggest that gaze initially operates like other directional cues but gradually acquires additional properties modulating the underlying dynamic.

Dynamic and Neural Evidence

Some studies have provided important observations about the temporal dynamics of the RCE, and others have further examined its neural bases. As mentioned earlier, embedding arrows in mosaic backgrounds eliminated the typical SCE or occasionally induce an smaller reversal, while gaze continued to elicit a robust RCE (Román-Caballero et al., 2021a; Y. Tanaka et al., 2024). This pattern was interpreted as a consequence of increase figure-ground segregation demands: when targets are presented within complex backgrounds (e.g., mosaic patterns or eyes within faces), participants must first extract the directional information. This delay creates a temporal gap between relevant and irrelevant codes, allowing the irrelevant location code to decay before it can interfere with response selection, thereby reducing spatial interference (see *temporal-delay hypothesis;* Hommel, 1993). A subsequent gaze-specific mechanism can then elicit the reversal (Román-Caballero et al., 2021a).

Extending this approach, Román-Caballero et al. (2021b) manipulated the synchrony of target and background presentation. When background and targets appeared asynchronously (target after the background), arrows elicited a clear SCE, whereas in the synchronous condition (target and background together) this effect was reduced. For gaze, the reversal was absent in the asynchronous condition but emerged

robustly when target and background were presented simultaneously. This pattern reinforces the assumption that when the SCE is weakened, the contribution of later gaze-specific component becomes more prominent, ultimately inverting the congruency effect.

Hemmerich et al. (2022), added a further layer by examining trial-by-trial dynamics through congruency sequence effects (CSE), i.e., whether the RCE is modulated by the congruency of the preceding trial. Although overall arrows and gaze produced opposite congruency effects (SCE and RCE, respectively), both effects were similarly modulated by sequential effects (i.e., congruency of the previous trial): for arrows, congruency effects decreased after incongruent trials (the classic CSE), whereas for gaze, the reversal was mainly elicited after incongruent trials, where a clear "reversed CSE" was observed. Importantly, these patterns emerged regardless of whether the preceding trial was social or nonsocial, further highlighting that the RCE increases in contexts where the SCE is reduced. Thus, the RCE was observed for social targets specially after incongruent trials, i.e., where the SCE observed for arrows was reduced or eliminated, no matter whether the previous trial used a social or a non-social target.

Further evidence for dissociable mechanisms underlying the RCE comes from electrophysiology. Marotta et al. (2019) compared gaze and arrow targets in a spatial Stroop while recording ERPs. Behaviorally, arrows and gaze yielded the typical dissociation respectively leading to the SCE and RCE. At the neural level, both stimuli showed similar modulations at early perceptual stages (P1, N1). In contrast, dissociations emerged at later stages: for arrows, incongruent trials elicited larger N2 and P3 amplitudes, consistent with conflict detection and increased control demands; for gaze, the opposite pattern was observed, with larger N2 and P3 amplitudes for congruent trials.

Converging evidence also comes from neuroimaging. Narganes-Pineda, Paz-Alonso, et al. (2023) used fMRI within the same setting. Both arrows and gaze recruited a shared set of fronto-parietal regions involved in conflict resolution, including the inferior and superior parietal lobes and the frontal eye fields, supporting the existence of a domain-general mechanism. However, distinct modulations were also observed: for gaze, congruent trials elicited stronger functional coupling between the right frontal eye field and ipsilateral occipito-temporal regions, whereas for arrows, incongruent trials

increased connectivity between the right frontal eye field and contralateral parietal and temporal regions.

Within these four categories, beyond reaction time measures, accuracy data have provided complementary insights into the RCE. Several studies have reported a parallel dissociation, although not always significant, with gaze targets eliciting higher error rates in congruent than incongruent trials (Bonventre & Marotta, 2023, Experiment 1; Cañadas & Lupiáñez, 2012, Experiment 1; Ishikawa et al., 2021, Experiment 1; Marotta et al., 2018, 2019). In addition, gaze targets often elicit more errors than arrows (Aranda-Martín et al., 2023; Hemmerich et al., 2022; Ishikawa et al., 2025; Marotta et al., 2019; Narganes-Pineda, Chica, et al., 2023, Experiment 3).

In emotional expression studies, lower accuracy has been reported for happy, angry, and sad faces in congruent compared to incongruent trials (Torres-Marín et al., 2017, Experiment 1), and angry faces consistently yielded more errors than other expressions (Marotta et al., 2022; Torres-Marín et al., 2017). Individual differences further modulate accuracy: Torres-Marín et al. (2017, Experiment 1) observed higher error rates in gelotophobes, while Marotta et al. (2022) reported that participants with low AQ scores made more errors with happy than with fearful faces. Developmental work showed that five-year-old children are more accurate with gaze than arrows, while by age twelve the opposite is true (Aranda-Martín et al., 2022).

Taken together, the evidence shows that the RCE is both robust and malleable. It cannot be reduced to a single process but reflects the interplay of perceptual demands, task goals, temporal dynamics, social meaning, and individual differences. This conclusion is supported not only by behavioral measures but also by converging electrophysiological and neuroimaging evidence. These findings set the stage for theoretical accounts that attempt to explain the mechanisms behind the RCE.

1.4.3. Theoretical Accounts of the RCE: Social, Non-Social, and Integrative Perspectives

Explaining the complexity of the RCE has required a range of theoretical perspectives. Broadly, accounts have been grouped into social explanations, which attribute the reversal to mechanisms tied to gaze and its communicative significance (Cañadas & Lupiáñez, 2012; Edwards et al., 2020; Hemmerich et al., 2022; Marotta et al.,

2018), and non-social explanations, which emphasize perceptual discriminability (Z. Chen et al., 2022), and task demands (Y. Tanaka et al., 2024).

Within social explanations, the eye-contact and joint attention hypotheses both assume that facilitation in incongruent trials underlies the RCE. The eye-contact hypothesis, already described in **Section 1.4.1.**, proposes that the effect reflects the enhanced salience of being looked at: incongruent trials direct gaze toward fixation, producing an episode of perceived eye contact that facilitates responses and reverses the usual Stroop pattern (Cañadas & Lupiáñez, 2012; Marotta et al., 2018).

The joint attention hypothesis makes a similar prediction but interprets the effect in terms of shared attentional focus. Incongruent trials facilitate performance because gaze is directed toward the observer's fixation, creating the impression that both are attending to the same location. Edwards et al. (2020) tested this idea by manipulating fixation eccentricity and the nature of the fixation point (**Section 1.4.2.**). Assuming that joint attention is object-based, replacing the central cross with a meaningful object should enhance the effect. Indeed, facilitation was observed whenever gaze aligned with the attended object, whether centrally or peripherally located. However, with a standard fixation cross, facilitation was restricted to inward gaze under central fixation.

By contrast, the joint distraction hypothesis assumes that the RCE arises from a cost in congruent trials rather than facilitation in incongruent ones. Hemmerich et al. (2022) argued that congruent gaze distracts attention away from fixation, slowing responses when participants must redirect focus to the center. For example, a right looking gaze presented to the right would lead the participants' attentional focus out of the task environment, further to the right, thus needing extra time to refocus attention back to the task's environment.

Overall, social accounts have characterized the RCE as a product of privileged gaze processing. This view is supported by evidence that the reversal reliably occurs with gaze but not with other typical directional cues (**Section 1.4.2.**), and by findings consistent with the communicative significance of gaze (**Section 1.3.1.**). Emotional expressions further modulate the effect, potentially through their approach-avoidance communicative features (Jones, 2015). Interactions with individual traits, such as gelotophobia, autistic traits, and social anxiety, also highlight the role of social-emotional

factors in shaping the RCE (Ishikawa et al., 2021; Marotta et al., 2022; Torres-Marín et al., 2017). Likewise, familiarity with the target and social experience with them also appears relevant, as the reversal has been observed with human and familiar domestic animal faces with which we likely have some experience interacting with, but not with robots or less socially communicative stimuli (Ishikawa et al., 2025).

However, some of these assumptions have been challenged. For instance, the eye-contact hypothesis presumes that facilitation is reflexive and automatic. Yet Narganes-Pineda, Chica, et al. (2023) found that the RCE emerged only when participants explicitly judged gaze direction. If the effect were driven solely by an automatic eye-contact mechanism, it should also appear under implicit task conditions (when judging color). Similarly, joint attention is typically linked to behaviors emerging in early development (Mundy et al., 2007), whereas the RCE does not appear until late childhood (Aranda-Martín et al., 2022). With regard to the joint distraction hypothesis, Aranda-Martín et al. (2023) attempted to reduce distraction by shifting participants' focus to the color indicated by the looked target rather than its direction (see **Section 1.4.2.**). On each side a colored bar was presented on each side of the screen, and participants were instructed to report the color of the bar the indicated or looked at by the peripheral arrow or gaze. As participants were to pay attention to the colored bar, attention should not go beyond the two flanking bars, and therefore no extra distraction should be observed by the gaze. However, this manipulation did not modulate the RCE, calling the joint distraction hypothesis into question.

In addition, modulation by emotional expressions may reflect perceptual rather than social factors. Although faces, including emotions, are typically processed holistically (see **Section 1.3.1.**), the spatial Stroop may disrupt holistic integration, as the RCE has been observed even with inverted faces (Marotta & Lupiáñez, 2018; Y. Tanaka et al., 2023). This suggests that expressions may influence the effect through morphological variations, such as changes in eye shape, rather than its general communicative meaning (Y. Tanaka et al., 2023). Such findings also challenge the eye-contact and joint attention accounts, since inverted faces would be expected to disrupt these episodes (Böckler et al., 2015; Senju et al., 2008; Tipples, 2005). A similar reasoning applies to studies using animal

faces, where differences in eye-surrounding features may influence the RCE through perceptual inputs rather than social familiarity (although see, Aranda Martín, 2023).

Alongside these challenges, alternative explanations have been advanced to attribute the RCE to perceptual or task-related mechanisms rather than to social significance. For example, Z. Chen et al. (2022) argued that differences between gaze and arrows may stem from how easily the directional information can be perceived (**Section 1.4.2.**). On this account, the RCE emerges when the perceptual characteristics of stimuli force participants to adopt different attentional "zoom" settings (see *zoom lens model;* Eriksen & St James, 1986). Eyes, being harder to discriminate, induce a narrower attentional focus that weakens irrelevant spatial codes and reduces interference. Under these conditions, the balance between relevant and irrelevant information can invert the standard congruency pattern.

The zoom lens framework has been influential in selective attention research, showing that attentional focus can be dynamically adjusted to optimize processing (Z. Chen & Cave, 2016; Z. Chen & Chan, 2007; LaBerge et al., 1991). This principle has been applied to conflict tasks, particularly the flanker task, where narrowing the focus enhances target selection and reduces interference from flankers (Hübner et al., 2010; White et al., 2011), even if it does not typically lead to a reversion of the effect.

Thus, applying this explanation to the spatial Stroop task raises challenges. Many of the studies cited by Z. Chen et al. (2022) used letters or letter-like symbols as targets and distractors (Z. Chen & Cave, 2016; Z. Chen & Chan, 2007; LaBerge et al., 1991), which do not involve spatial information, the critical source of conflict in location-based tasks (**Section 1.2.2.**). In the spatial interference paradigm, relevant direction and irrelevant location are embedded within the same stimulus without explicit boundaries, and the abrupt onset of the stimulus itself is assumed to elicit conflict, conditions that likely engage additional mechanisms beyond attentional focus. Still, because the task also involves S-S overlapping, the zoom lens account may capture part of the phenomenon during stimulus processing stage.

A second non-social explanation was proposed by Y. Tanaka et al. (2024). They argued that the effect reflects the operation of two successive processing stages. In the first stage, target-background segregation delays the extraction of directional

information, weakening the impact of irrelevant spatial codes and thereby reducing interference. In the second stage, a later inhibitory process can actively suppress residual location codes, consistent with the *activation-suppression* hypothesis (Ridderinkhof, 2002). This suppression, potentially via a negative priming mechanism operating within the trial, may invert the usual congruency pattern.

Evidence for the first stage comes from Román-Caballero et al. (2021a, 2021b), who directly tested background segregation and observed a reduction of spatial interference. The account also builds on inhibitory control models widely used to explain performance in location-based tasks, where stimulus onset automatically activates location-based responses that, when in conflict with task-relevant information, are thought to be actively suppressed (Ridderinkhof, 2002a, 2002b). Moreover, the robust RCE observed with tongues, introduced in **Section 1.4.2.**, is notable because it is unlikely to rely on gaze-specific mechanisms.

At the same time, several findings further complicate this account. Although tongues may challenge gaze-based explanations, they can also be considered social stimuli. The mouth region is an important feature in face processing (Itier & Preston, 2018; S. Luo et al., 2013), and tongue protrusion functions as an early communicative signal in development (Anisfeld, 1996; Forrester & Rodriguez, 2015). Tongues also carry communicative value in emotional contexts (Rozin et al., 1994) and have been shown to cue attention in orienting tasks (Downing et al., 2004). These observations raise the possibility that social mechanisms still contribute.

Furthermore, attempts to extend the dual-stage framework to non-social cues have produced mixed results. Arrows embedded in complex backgrounds did not yield a reliable reversal (cf., Román-Caballero et al., 2021a, 2021b; Y. Tanaka et al., 2024, Experiment 3). Likewise, in a later study, arrows and fish embedded in mosaic background failed to elicit mean-level RCEs, with distributional analyses revealing only partial reversals in specific portions of the RT distribution, whereas gaze elicited a robust RCE across the full distribution (Y. Tanaka et al., 2025).

These limitations suggest that while perceptual discriminability and task-related mechanisms contribute to the effect, they cannot fully explain some aspects of the RCE. Both sets of accounts may therefore capture different facets of the phenomenon but

remain incomplete when considered separately. Rather than competing, these perspectives appear to address complementary stages of processing.

Some researchers had already suggested an integration of social and non-social factors (Marotta et al., 2018, 2019; Román-Caballero et al., 2021b, 2021b), and Hemmerich et al. (2022) formalized this view by explicitly proposing an account based on the interplay of shared and unique mechanisms. Their account emphasizes that arrows and gaze initially recruit similar spatial interference processes, as supported by early ERP components (Marotta et al., 2019). However, gaze additionally triggers a gaze-related component (the "looking vector"), which can override the SCE and elicit the reversed effect, reflecting that eyes do not merely point but actively "look" at a location. In this way, the RCE emerges as the joint outcome of shared conflict dynamics and a socially grounded mechanism unique to gaze.

Extending this perspective, Aranda Martín (2023) positioned gaze stimuli along a continuum of complexity. At one extreme, expressive faces (e.g., angry or happy) increase the difficulty of extracting directional information while also amplifying the communicative signal. At the other extreme, cartoon eyes provide easily accessible directional cues but weak social meaning, making their processing more similar to arrows. On this continuum, the strength of the looking vector reflects the interplay between perceptual and social factors: expressive faces combine perceptual difficulty with heightened communicative relevance, further reducing spatial interference, whereas cartoon eyes elicit weaker social processes and a diminished looking vector.

An important next step would be to integrate recent findings on non-social stimuli within this continuum. While such targets have occasionally elicited the RCE, the evidence indicates that social stimuli (e.g., gaze and tongues) continue to play a distinctive role in shaping its expression. At the same time, given that gaze plays a fundamental role across multiple stages of cognitive processing (Stephenson et al., 2021; Yang et al., 2015), it would be premature to discard it, at least, as a key modulator of the effect. Nevertheless, perceptual and task-related factors clearly contribute to shaping the RCE. Thus, even if gaze is not the sole stimulus capable of producing the reversal, it may enhance or amplify it, and the lack of a robust reversal with non-social cues further

suggests that social targets naturally possess the conditions required to trigger this phenomenon.

To better capture this interplay, the dual-route framework provides a useful model, as it is designed to explain how task-relevant and irrelevant information compete during processing. This makes it particularly suitable for social stimuli, whose complex configuration may yield not only directional cues but also multiple layers of irrelevant information in a spatial Stroop setting, such as spatial, morphological, or communicative.

1.4.4. The dual-route framework and the distributional approach

The dual-route framework has become an important account for explaining performance in conflict tasks such as the Stroop, Simon, and flanker paradigms (Cohen et al., 1990; De Jong et al., 1994; Hommel, 1993; Lu & Proctor, 1995; Ridderinkhof, 2002a). As described briefly in **Section 1.2.2.**, its central premise is that information is processed along two parallel pathways that can either converge or compete depending on task demands. This makes it especially relevant for the RCE, where social stimuli are likely to engage additional sources of information beyond spatial and directional codes.

Within this framework, the automatic route is fast and stimulus-driven, activating responses based on irrelevant features, while the controlled route is slower and more deliberate, guiding responses according to the instructed stimulus–response mapping. Congruent trials benefit from the convergence of both routes, whereas on incongruent trials the automatic route initially drives the wrong response, which must then be overridden by the controlled process (Ulrich et al., 2015).

Two main mechanisms have been proposed for conflict resolution. One emphasizes active suppression, whereby irrelevant activation is counteracted by a top-down inhibitory mechanism that builds up over time, adapting its onset, strength, and rate (Ridderinkhof, 2002a). The other assumes that automatic activation is inherently short-lived and decays naturally after reaching a peak, if it is not used to quickly execute a response (Hommel, 1993; Ulrich et al., 2015). These perspectives need not be mutually exclusive (White et al., 2018). Different aspects of tasks may rely more heavily on one mechanism than the other, underscoring the flexibility of the dual-route framework (Ellinghaus et al., 2024; Mittelstädt & Miller, 2020; Ulrich et al., 2015). In this sense, it can be seen as a task-specific instantiation of the broader weighting system described in

Section 1.1., where competing inputs are dynamically prioritized or down-weighted depending on goals, salience, and context.

To examine these mechanisms in detail, researchers have relied on distributional analyses (Balota & Abrams, 1995; De Jong et al., 1994; Mittelstädt & Miller, 2020). For the purposes of this thesis, the two most relevant tools are the Conditional Accuracy Function (CAF), and the delta function.

CAFs analyze accuracy as a function of execution time by dividing the RT distribution into bins, defined as intervals between quantile cut-points. Accuracy is then calculated within each bin, from the fastest to the slowest responses. This reveals whether errors cluster in early or late responses, offering a functional index of when the automatic route dominates versus when control mechanisms have time to act (Heitz, 2014).

In conflict tasks, CAFs typically show that the fastest incongruent responses are disproportionately error-prone, a pattern known as automatic response capture (Salzer et al., 2019; Torres-Quesada et al., 2022; van Campen et al., 2018). As responses slow, accuracy improves, reflecting the corrective influence of inhibitory processes or the decay of irrelevant codes. Their shape can be modulated by factors such as target discriminability and task demands (Ellinghaus et al., 2024; Hübner & Töbel, 2019).

Delta functions provide a complementary perspective by quantifying how the size of the congruency effect measured with RT changes across the RT distribution (De Jong et al., 1994). Derived from the cumulative distribution function and implemented through quantile averaging (Ratcliff, 1979), RTs are ordered from fastest to slowest, divided into quantiles for congruent and incongruent trials and the difference between them is computed. Functionally, this captures how interference unfolds across response speed.

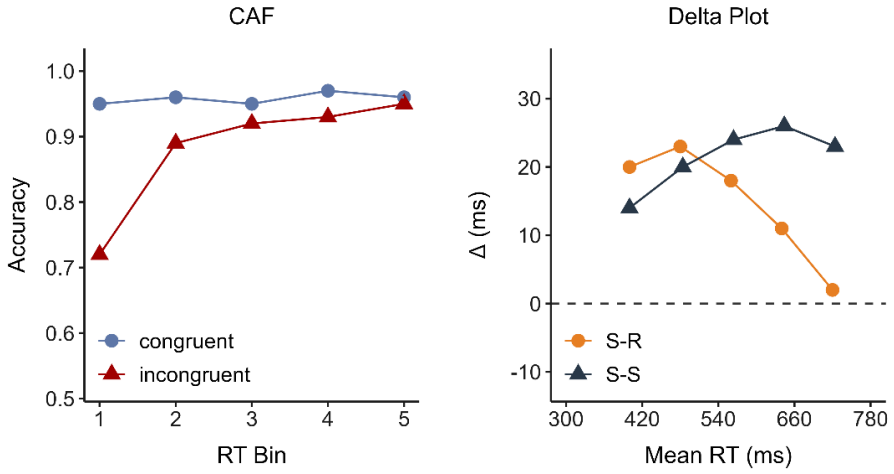
Classic findings show that congruency effects are largest for the fastest responses, where the automatic route exerts the strongest influence and the interference increases, and then decline as inhibitory mechanisms suppress irrelevant activation or as spatial codes fade (Mittelstädt et al., 2022; Mittelstädt & Miller, 2020; Ridderinkhof, 2002b; Ulrich et al., 2015). Accordingly, the slope of the delta curve provides further insight: steeper declines indicate effective control or decay, whereas flatter curves suggest more persistent interference.

Beyond these general patterns, delta functions have been used to distinguish between different conflict structures. Distinct profiles emerge depending on whether interference arises primarily from S-S or from S-R overlap (C. Luo & Proctor, 2017; Scerrati et al., 2017; Torres-Quesada et al., 2022).

To facilitate later interpretations, **Figure 5** depicts the typical patterns of CAFs and usual patterns observed in delta plots.

Figure 5

Typical Patterns of CAFs and Delta Plots in Conflict Tasks



Note. CAF (left) plots accuracy across RT bins (from the fastest to the slowest responses), typically showing disproportionately more errors for incongruent trials among the fastest responses. The delta plot (right) shows the congruency effect (incongruent minus congruent RT) across RT quantiles; steeper declines indicate stronger control/decay, flatter curves more persistent interference. The S–S and S–R patterns follow Scerrati et al. (2017).

Overall, the utility of CAFs and delta function highlights why distributional tools can be informative for examining the mechanisms underlying the RCE. In social attention research, some studies have already interpreted their results within this framework (Z. Chen et al., 2022; Narganes-Pineda, Chica, et al., 2023; Román-Caballero et al., 2021a, 2021b; Y. Tanaka et al., 2024), providing a valuable starting point. However, systematic applications of distributional methods to the RCE have only recently begun to emerge. The present thesis contributes to this growing line of work by examining the temporal dynamics of the reversal within the dual-route framework using a distributional approach.

These issues will be revisited across the studies presented here and further discussed in the General Discussion (**Chapter V**), where they will be integrated with recent findings in the literature.

CHAPTER 2. MOTIVATION, AIMS, AND OVERVIEW OF THE RESEARCH

2.1. Motivation & Aims

The introduction established that spatial interference paradigms, and in particular the spatial Stroop task, provide a valuable tool for investigating how relevant and irrelevant information interact during response selection.

Within this framework, gaze is especially intriguing because it combines directional cues with strong social meaning, while its complex perceptual configuration can simultaneously introduce additional layers of task-irrelevant information arising from its morphological and communicative features. This multifaceted nature makes gaze an ideal candidate for testing whether attentional control and orienting effects elicited by social stimuli are governed solely by domain-general mechanisms, or whether they can also be modulated or triggered by socially related processes.

A central phenomenon that captures this debate within the spatial Stroop task is the RCE. Whereas arrows and other non-social stimuli typically produce an SCE, i.e., faster responses when stimulus direction and spatial location are congruent, gaze stimuli often show the opposite pattern, with incongruent trials eliciting faster responses (**Section 1.4.2.**). This dissociation has been addressed by both social and non-social accounts (**Section 1.4.3.**), yet for the present work the emphasis lies on the integrative view (Hemmerich et al., 2022; Marotta et al., 2019; Román-Caballero et al., 2021b, 2021a). This account provides a valuable starting point, but it should be further expanded in light of new findings to capture more precisely the joint contributions of perceptual, task-related, and social mechanisms, as well as their interactions.

One possible way to further develop this expanded account is to embed these findings within the general framework described in **Section 1.1.1.**, where attentional mechanisms are conceptualized as a dynamic system of weights and balances (Narhi-Martinez et al., 2023). In this view, stimuli exert differential influence on processing, and attention continuously adjusts their relative priority. Building on this foundation, the dual-route framework, with its distributional tools, offers a concrete approach to conflict and resolution research by examining how stimulus features and task-related aspects shape the relative weights of relevant and irrelevant information (**Section 1.4.4.**).

From this perspective, these frameworks also provide a natural bridge for interpreting the empirical evidence accumulated so far, which already allows for a

preliminary profile of the reversal when contrasted with the typical Stroop pattern. Overall, findings suggest that the RCE does not stem from a single source of spatial interference but may arise through different mechanisms. The robust effects observed with social stimuli such as gaze and tongues underscore that social influences cannot be ignored. Moreover, the extensive literature on the role of gaze as a socio-communicative signal, processed from perceptual to higher-order levels, supports the idea that it may introduce unique modulations into the dynamic underlying this phenomenon.

At the same time, perceptual manipulations, such as changes in stimulus perceivability and conditions that hinder the extraction of task-relevant information, along with task-related manipulations, including shifts in participants' focus on instructions, the placement of the fixation cross, and variations in response-mapping rules, have all been shown to alter its dynamics (**Section 1.4.2.**). Furthermore, the occasional reversals observed with non-social stimuli highlight the importance of perceptual and task-related factors in triggering this phenomenon.

In addition, analyses of the temporal dynamics add another layer, pointing to shared early mechanisms followed by a later dissociation. They also suggest a reciprocal relationship between the SCE and RCE, such that one decreases as the other increases, implying that the SCE must first be reduced for the RCE to emerge.

Together, this points to the RCE as a multi-stage phenomenon, shaped jointly by social and non-social components. Two interpretations can be drawn from these considerations:

1. Distinct RCE profiles may exist, each tied to a particular class of stimuli (e.g., eyes, faces, tongues, and potentially some non-social cues). This would align with the extensive literature granting faces and their features (eye and mouth regions) a privileged status across perceptual and higher-order levels of processing, as well as with reversals observed in some non-social targets.
2. Alternatively, reversals may be facilitated by domain-general mechanisms that social targets naturally engage. In this view, the central question becomes which features of social stimuli enable them to disrupt typical Stroop dynamics, and whether such features can be artificially replicated in non-social stimuli with the same robustness.

The latter possibility has already received preliminary support: reversals have been reported with infinity symbols and arrows, and at the distributional level with arrows and fish (**Section 1.4.2.**). These findings suggest that non-social stimuli can, under certain constraints, approximate the effects typically associated with social stimuli. This is particularly relevant given proposals that faces are processed much like any other object, with their distinctive patterns reflecting humans' high level of expertise rather than an intrinsic specialization (Gauthier et al., 2003; Wang et al., 2016).

However, these non-social RCEs remain weak and inconsistent. This lack of reliability underscores the need for a systematic investigation into the conditions under which the RCE emerges, and whether its occurrence is truly tied to social stimuli or can be replicated through non-social manipulations.

Building on these insights, the present thesis aims to investigate the extent to which task-related and perceptual mechanisms contribute to the RCE, while also examining the unique contribution of social targets. The studies will pursue two main goals:

1. Profiling the RCE across gaze and arrows by employing a distributional approach within the dual-route framework, thus providing a nuanced account of the behavioral temporal dynamics of task-relevant and -irrelevant processing.
2. Testing whether non-social stimuli can elicit RCE-like patterns by mimicking key features of social targets, especially gaze, in order to determine whether the reversal is exclusive to social stimuli or can be induced through carefully designed perceptual manipulations.

This thesis does not attempt to cover all possible manipulations identified in **Section 1.4.** Instead, it focuses on extending previous research by examining the interplay between social, perceptual, and task-related mechanisms, applying a distributional approach within the dual-route framework, and outlining directions for further work.

2.2. Overview of the Research

This thesis addresses the above aims through a series of empirical studies, each designed to test complementary aspects of the RCE. Together, these studies move from exploratory distributional characterization of the phenomenon to experimental tests of its boundary conditions and examining whether non-social manipulations can replicate it.

The four main studies are presented in **Chapter III.** The first two provide a distributional characterization of previously published datasets, focusing on CAFs (**Study 1**) and delta functions (**Study 2**). The subsequent experimental studies extend this approach employing two experimental manipulations with non-social stimuli: **Study 3** varies target features, and **Study 4** increases perceptual complexity.

In addition to these four main studies, an additional pre-cueing study was conducted during the doctoral research period to examine how attentional orienting and alerting states modulate spatial interference. Although not part of the main series, this project provides an extension about the RCE characteristics by exploring the relationship between the SCE and the RCE, which are briefly discussed in the **General Discussion**.

The following paragraphs describe each study in turn, followed by a summary of the pre-cueing study. The chapter then concludes with a note on publication status and open-science practices, and a description of complementary analyses reported in the Appendices, which provide additional exploratory insights relevant to the main findings.

Study 1

This study examined the temporal dynamics underlying the dissociation between social and non-social targets in the spatial Stroop task. Most prior analyses and interpretations have focused on RT rather than accuracy, yet several studies have reported informative error-rate patterns (**Section 1.4.2.**). Accordingly, it was deemed important to trace how these patterns unfold across the RT distribution; CAFs were therefore introduced as the distributional tool.

To provide a broad, comparable baseline rather than rely on a single dataset**,** re-analyses of previously published spatial Stroop datasets were conducted, combining 16 experiments from 11 studies (N = 705 participants). Guided by prior work, the typical pattern for non-social targets, reduced accuracy for the fastest incongruent responses

with recovery across slower bins (see **Figure 5**), served as the benchmark. For social targets, at the time no CAF analyses had been reported to ground specific predictions; nevertheless, because CAF modulations are typically most pronounced among the fastest responses, social stimuli were expected to alter this early portion of the distribution.

The study addressed the thesis aims through three specific objectives: (i) to profile CAFs for social versus non-social targets to detect early-stage dissociations; (ii) to separate faces from isolated eyes and assess whether broader facial context (i.e., more complex background) shifts the locus of modulation; and (iii) to explore whether facial expressions further shape these patterns.

Additional details and complementary analyses are provided in the Supplemental Materials (**Appendix A**).

Study 2

This study complements Study 1 by characterizing the time course of the congruency effect using cumulative distribution functions (CDFs) and delta functions. Beyond mean RTs, CDFs trace condition-wise latencies across quantiles, while delta functions index changes in conflict over time (**Section 1.4.4.**). Applied to the spatial Stroop, these tools test where reversal-like patterns are most likely to emerge and how their trajectory compares with the non-social SCE.

The same combined datasets used in Study 1 were re-analyzed (16 experiment; 11 studies; N = 705). Based on prior work with location-based tasks, non-social targets typically show the largest effects among the fastest responses, with diminishing effects at slower quantiles (**Figure 5**); a similar pattern was anticipated for the SCE. For social targets, and in line with recent work , an increasing RCE across quantiles was expected, becoming more negative. In addition, separating faces and isolated eyes (as in the CAF analyses) was expected to reveal distinctions at both the mean and distributional levels, given that facial context (greater perceptual complexity) may produce differential modulations.

Study 2 therefore had three specific objectives: (i) to profile how the congruency effects unfolds across quantiles for social (faces, eyes) versus non-social (arrows) targets; (ii) to determine when reversal-like patterns emerge and how their delta-plot trend (e.g.,

negative-going slopes or quadratic components) evolve; and (iii) to compare faces versus eyes across the distribution, assessing whether added facial context shifts the timing and magnitude of the RCE.

Additional details and complementary analyses for Study 2 are provided in the Supplemental Materials (**Appendix B**).

Study 3

This study tested whether the RCE can be reproduced with non-social targets by manipulating target features alone. The study was motivated by the idea that gaze may introduce low-level perceptual asymmetries (iris-sclera contrast). Note, that a right looking gaze would have the more salient sclera to the left of the iris, to which participants needs to respond "right". This asymmetry might interact with direction and location spatial codes elicited by the gaze, and we questioned whether this asymmetric contrast polarity is sufficient to induce reversal-like patterns in a spatial Stroop task. The rationale drew on prior work highlighting the importance of perceptual features for processing gaze direction (**Section 1.3.1.**). A distributional approach was used to locate when any reversal would arise within the RT distribution.

Two preregistered experiments implemented these manipulations. Experiment 1 varied the contrast polarity of arrows targets: *gaze-similar* (darker head/lighter tail, mimicking iris-sclera asymmetry) versus *gaze-opposite* (lighter head/darker tail). Experiment 2 added a perceptual-complexity factor by embedding arrows in a visually complex background, testing whether increased complexity down-weights the shared SCE, as observed in previous studies (**Section 1.4.2.**), and unmasks potential reversal-like dynamics for contrast-manipulated arrows.

The specific objectives were: (i) to determine whether contrast polarity alone can elicit an RCE with arrows; (ii) to assess whether added perceptual complexity reduces spatial interference sufficiently to reveal reversal-like patterns; and (iii) to characterize the time course of any effects via CAFs and delta plots, comparing gaze-similar versus gaze-opposite targets across the RT distribution.

Study 4

This study addressed the same question as Study 3, i.e., whether the RCE can arise without social content, by making access to arrow direction sufficiently difficult, as suggested by non-social accounts (**Section 1.4.3.**). The core idea was that visual masking (i.e., added perceptual complexity) may hinder extraction of task-relevant direction, altering the balance between task-irrelevant spatial codes and control. As in Study 3, a distributional approach was used to determine when any reversal would emerge.

Two preregistered experiments evaluated this proposal. Experiment 1 varied masking level on arrow targets (three difficulty levels) in a spatial Stroop task. Experiment 2 aimed to replicate and extend the patterns by (a) adding gaze targets and (b) manipulating target-type predictability via within-block (all target types intermixed) versus between-block (one target type per block) presentation. This manipulation was motivated by evidence that predictability can amplify or reduce conflict (e.g., Hübner & Mishra, 2013), allowing an assessment of whether predictability could account for any non-social reversal.

The study's objectives were: (i) to test whether perceptual masking alone can elicit an RCE with arrows; (ii) to examine whether trial-wise predictability (within- vs between-block) modulates interference by altering control mechanisms demands; and (iii) to compare masked arrows with gaze across the RT distribution, evaluating convergence or divergence in their distributional profiles.

Additional details and complementary analyses are provided in the Supplemental Materials (**Appendix C**).

Additional Study: Pre-Cueing Effects on Spatial Interference

This additional study independently manipulated spatial orienting (via peripheral pre-cues) and temporal alerting (via auditory warning signals) while participants performed a spatial Stroop task with gaze and arrow targets. Drawing on previous findings using similar manipulations (Funes et al., 2007; Funes & Lupiáñez, 2003), valid pre-cues were expected to reduce location-based conflict by pre-activating the correct spatial code, thereby decreasing the SCE for arrows and enhancing the RCE for gaze.

Conversely, alerting signals, by increasing general arousal, were predicted to strengthen interference, producing larger SCEs for arrows and attenuated RCEs for gaze.

This study therefore tested a key prediction of the integrative account: that gaze and arrows share a common interference component, but gaze adds an opposing mechanism whose expression depends on interference strength—enhanced when interference is reduced and weakened when it is increased. Two preregistered experiments tested these predictions, with additional preregistered extensions addressing the role of placeholders currently underway. Preliminary results are reported in **Appendix D** and briefly discussed in **Chapter IV** as part of the broader synthesis of processes underlying the RCE.

Notes on distributional analyses

The selection of bins for CAF and of quantiles for delta function analyses is not fixed in the literature, with studies typically dividing the RT distribution into between three and ten segments (Ambrosi et al., 2020; Hübner & Töbel, 2019; Van Maanen et al., 2019). In **Study 1**, different binning choices (4 and 5 bins) were systematically examined to ensure that potential modulations in the fastest portion of the RT distribution were not obscured by overly coarse partitioning. In **Study 2**, analyses were conducted using 4, 5, and 10 quantiles. The use of four quantiles allowed comparability with previous research in social attention (Y. Tanaka et al., 2025), whereas the five- and ten-quantile solutions enabled a more fine-grained examination of distributional dynamics.

After assessing the convergence, robustness, and interpretability of all approaches (see **Studies 1** and **2**), 5 bins/quantiles were selected as the standard for the main analyses reported throughout the manuscripts. This choice is consistent with several references cited in this thesis (e.g., Hübner & Töbel, 2019; Mittelstädt et al., 2022; Ulrich et al., 2015) and, importantly, provides a meaningful interpretive anchor: in a five-quantile distribution, the third quantile (0.5) corresponds to the median of the RT distribution, offering a clear midpoint for evaluating changes across the distribution.

Notes on publication status and open-science practices

The following chapters present the four studies that constitute this thesis; each has been published in a peer-reviewed journal or is currently under review, and all are

freely accessible, following open-science practices. Some overlap in background and methods across chapters is therefore unavoidable. Because the studies are reproduced in their published or submitted form, figures and tables retain their original format and numbering.

For the distributional analyses (**Studies 1** and **2**), they were explicitly framed as exploratory in order to building a distributional profile within the spatial Stroop paradigm. All datasets and analysis scripts are openly available on the Open Science Framework (OSF) repository: https://osf.io/twbs3/.

For the experimental studies (**Studies 3** and **4**), sample sizes were determined a priori via power-analysis procedures; all data exclusions, manipulations, and measures were reported in detail, including how each was determined. Hypotheses, experimental designs, and analysis plans were preregistered prior to completing data collection. Preregistrations, task materials, stimuli, datasets, and analysis scripts, are publicly available on OSF. **Study 3**: https://osf.io/wzkqb/; **Study 4**: https://osf.io/yvcak/. Preprints are also available for both studies, providing early access to the manuscripts. **Study 3**: https://osf.io/preprints/psyarxiv/d9nw4_v1; **Study 4**: https://osf.io/preprints/psyarxiv/ygdft_v2.

The pre-cueing study followed the same methodological and transparency standards. Its preregistration, task materials, analysis scripts, and preliminary results are openly available at https://osf.io/a4nqh/.

Finally, two supplemental and exploratory examinations are reported in the appendices. **Appendix E** reanalyzes data from Narganes-Pineda, Chica, et al. (2023) in the verbal explicit task using a distributional approach, while **Appendix F** provides a descriptive exploration of congruency effects in initial trials. These supplemental materials are not directly related to the main aims but serve as illustrative additions to some findings reported in this thesis and are used in the General Discussion to interpret the observed findings.

CHAPTER 3. EXPERIMENTAL SERIES

3.1. Study 1. Exploring the spatial interference effects by social and non-social targets: A conditional accuracy function approach

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Study 1 has been published as:

Ponce, R., Lupiáñez, J., González-García, C., Casagrande, M., & Marotta, A. (2025). Exploring the spatial interference effects elicited by social and non-social targets: A conditional accuracy function approach. *British Journal of Psychology*, 116(1), 69–88. https://doi.org/10.1111/bjop.12735

Abstract

Recent studies employing the spatial interference paradigm reveal qualitative differences in congruency effects between gaze and arrow targets. Typically, arrows produce a standard congruency effect (SCE), with faster responses when target direction aligns with its location. Conversely, gaze targets often lead to a reversed congruency effect (RCE), where responses are slower in similar conditions. We explored this dissociation using the Conditional Accuracy Function (CAF) to assess accuracy across reaction time bins. Using a hierarchical linear mixed modelling approach to compare cropped eyes, and full faces as social stimuli, and arrows as non-social stimuli, we synthesized findings from 11 studies, which led to three distinct models. The results showed that with non-social targets, incongruent trials exhibited lower accuracy rates in the first bin than in subsequent bins, while congruent trials maintained stable accuracy throughout the distribution. Conversely, social targets revealed a dissociation within the fastest responses; alongside a general reduction in accuracy for both congruency conditions, congruent trials resulted in even lower accuracy rates than incongruent ones. These results suggest with gaze targets that additional information, perhaps social, in addition to the automatic capture by the irrelevant target location, is being processed during the earlier stages of processing.

Key words: conditional accuracy function, distributional analysis, gaze versus arrows, social attention, spatial interference effect

Introduction

The current debate in social attention research focuses on whether social orienting, which involves focusing on where others look or pay attention to, is influenced by general attentional mechanisms linked to stimulus directionality, such as eye-gaze direction (Cole & Millett, 2019), or by rather specific social processes related to attributing intentions and mental states (Apperly & Butterfill, 2009). To explore this issue, researchers has recently employed the spatial interference paradigm (Cañadas & Lupiáñez, 2012; Jones, 2015; Marotta et al., 2018) using spatial Stroop-like tasks to examine whether social stimuli can specifically trigger attentional processes.

The spatial Stroop task examines the conflict between processing task-relevant information (i.e. direction of the stimuli), and irrelevant spatial information (i.e., physical location; see Lu & Proctor, 1995). In this task, participants must identify the direction of lateralized stimuli using lateralized responses while ignoring the spatial position. This set-up results in congruent trials (e.g. arrows pointing left presented on the left side) and incongruent trials (e.g. arrows pointing left presented on the right side). According to Kornblum's (1992) taxonomy, the spatial Stroop produces a Type 8 ensemble, with three-dimensional overlap between: (a) relevant and irrelevant stimulus dimensions, (b) relevant stimulus and the response dimensions and (c) irrelevant stimulus and response dimensions (see also Viviani et al., 2024).

Typically, non-social stimuli produce faster responses in incongruent trials than incongruent ones, resulting in a standard congruency effect (SCE). According to multiple-stage and multiple loci theories of Stroop interference (Banich, 2019; De Houwer, 2003; Parris et al., 2022a), this phenomenon occurs because participants must address, during incongruent trials, the conflict at various levels, including task, stimulus and response.

Interestingly, Cañadas and Lupiáñez (2012) observed that participants were faster in incongruent trials when responding to the direction of lateralized gaze stimuli, producing a reversed congruency effect (RCE). This pattern was later replicated (Jones, 2015; Torres-Marín et al., 2017) and compared with non-social stimuli such as arrows (Marotta et al., 2018), and other social cues such as pointing hands (Bonventre & Marotta, 2023; Dalmaso et al., 2023), with the reversion occurring only with eye-gaze. The RCE has also been observed with some animal faces (Ishikawa et al., 2025), inverted faces (Y. Tanaka et al., 2023) and using oral responses (Narganes-Pineda et al., 2023, experiment 3A). Intriguingly, Y. Tanaka et al. (2024) observed the reversion using tongues as directional targets, proposing a dual-route account, as described below.

To better understand the underlying mechanisms of this phenomenon, Marotta et al. (2019) conducted an electrophysiological study and found that early event-related components (P1, N1 and N170) are similarly influenced by congruency in both eye-gaze and arrow stimuli. However, opposite modulation patterns were observed in later components (N2 and P3). More recently, Narganes-Pineda et al. (2023), in an fMRI study, observed common activations for eye-gaze and arrow stimuli in right parieto-temporo-

occipital regions during conflict resolution, alongside distinct activations between the frontal eye field (FEF) and occipital regions.

From a behavioural perspective, Román-Caballero et al. (2021a, 2021b) found that variables reducing the SCE with arrows, such as the perceptual background complexity simultaneously increased the RCE for gaze trials. The necessary background segregation before selecting directional information created a temporal gap between processing relevant and irrelevant information. As a result, the irrelevant information decayed (*temporal-delay hypothesis;* Hommel, 1993), reducing the spatial conflict, subsequently increasing the RCE observed for gaze targets. Hemmerich et al. (2022) found that arrows and words elicited a typical congruency sequence effect (see Gratton et al., 1992; i.e. decrease of the SCE after incongruent trials), whereas eye-gaze and faces led to a similar increase of the RCE after incongruent trials. Importantly, the increase in the RCE was observed even when the arrow and gaze targets were presented mixed within the same block. Notably, RCEs increased with social, and SCEs decreased with non-social stimuli following incongruent trials, regardless of the nature of the previous target. Additionally, a developmental study revealed that while a typical SCE was already observed in 4-year-olds and persisted throughout childhood for both eye-gaze and arrows, the RCE only became evident for eye-gaze stimuli from the age of 12 years (Aranda-Martín et al., 2022).

Based on these observations, a recently introduced integrated framework for the RCE observed with gaze considers both domain-general attentional processes and domain-specific mechanisms (Hemmerich et al., 2022). Specifically, domain-general attentional processes linked to the stimulus' pointing direction and its spatial location would produce similar spatial interference conflict for arrows and gaze, leading to faster responses for congruent conditions. In contrast, additional 'special' processes (e.g., the 'looking vector'; Hemmerich et al., 2022) occur only with eye-gaze, resulting in either slower responses for congruent or faster responses for incongruent gaze conditions, thus reversing the overall spatial conflict. Nevertheless, the exact 'special' mechanisms that modulate the interaction between task-relevant and irrelevant information and are ultimately responsible for the RCE are still subject to ongoing debate.

Two main theoretical approaches have been explored to understand the phenomenon. The first emphasizes the importance of a social component. Initially, the

eye-contact hypothesis was proposed (Cañadas & Lupiáñez, 2012; Marotta et al., 2018), suggesting that participants would implicitly interpret the eyes in the incongruent condition (e.g. left eyes looking right) as looking at them, facilitating faster responses in incongruent trials. However, Narganes-Pineda et al. (2023) demonstrated that explicit attention to the direction of eye-gaze is essential for the RCE to occur, challenging the automaticity of the eye-contact premise. Alternatively, Edwards et al. (2020) suggested that the RCE could be due to a joint attention episode (i.e. incongruent eyes would 'look' at fixation where participants are fixating). Despite this, the reversal was absent in children under 12 years (Aranda-Martín et al., 2022), even though joint attention typically occurs before 4 years (Mundy et al., 2007). More recently, the joint distraction hypothesis was proposed (Hemmerich et al., 2022), claiming that congruent trials cause attention to shift away from the task, requiring a reorientation of attention and thereby slowing down reaction times. However, recent experiments have not supported this theory; Aranda-Martín et al. (2023) used objects or external frames to prevent distraction, but the RCE was not modulated.

Despite the contrasting findings, there is still some evidence that supports the social interpretation of gaze underlying the reversed effect. The RCE seems influenced by the emotional expressions of faces (Jones, 2015; Marotta et al., 2022; Torres-Marín et al., 2017), modulated by social familiarity (Ishikawa et al., 2025) and negatively correlated with social anxiety scores (Ishikawa et al., 2021).

Alternatively, a second theoretical approach suggests non-social explanations based on either perceptual factors (Z. Chen et al., 2022) or task-related effects . For instance, Z. Chen et al. (2022) observed that stimuli with equivalent perceptual features, regardless of their social versus non-social nature, resulted in the SCE (although see Cañadas & Lupiáñez, 2012). This implies that congruency effects, whether elicited by eye-gaze or arrow stimuli, are largely shaped by their perceptibility. Additionally, they suggested that variations noted in other studies could be attributed to changes in the breadth of attentional focus, as outlined by the zoom lens model of attention (Eriksen & St. James, 1986).

On the other hand, Y. Tanaka et al. (2024, 2025) introduced a dual-stage theory, suggesting that a target background segregation and subsequent selective attention

processes play a role in the reversion of the spatial congruency effect. According to this theory, the segregation of a target from its complex background delays the extraction of the target's directional information, as outlined by Román-Caballero et al. (2021a, 2021b), allowing the location code to decay (Hommel, 1993). Following this segregation, selective attention acts to suppress the irrelevant spatial code, thereby resolving conflict (*activation-suppression hypothesis*; Ridderinkhof, 2002a, 2002b). In the congruent condition, where the spatial code aligns with the directional code – such as when right-looking gaze is presented in the right visual field – selective inhibition mechanisms suppress the correct spatial code (right), which delays the response. Conversely, in the incongruent condition, such as when a gaze directed to the right appears in the left visual field, selective inhibition suppresses the incorrect spatial code for the location (left), speeding up the correct response (right).

These two general frameworks' accounts (social vs. non-social) are usually based on reaction time analyses, sometimes resulting in neglecting the analysis of accuracy rates (Dalmaso et al., 2023; Jones, 2015; Y. Tanaka et al., 2023, 2024). However, although not always statistically significant, a dissociation in congruency effects between arrows and gaze has also been observed when considering error rates (Bonventre & Marotta, 2023, experiment 1; Cañadas & Lupiáñez, 2012, experiment 1; Ishikawa et al., 2021, experiment 1; Marotta et al., 2018, 2019).

Additionally, a consistent finding has been that participants generally make more errors in discriminating gaze direction than in discriminating arrows direction (Aranda-Martín et al., 2023; Hemmerich et al., 2022; Ishikawa et al., 2025, experiments 3 & 4; Marotta et al., 2019; Narganes-Pineda et al., 2023, experiment 3). Interestingly, 5-year-old children had higher accuracy rate with eye-gaze than with arrows stimuli, while 12-year-olds had the opposite pattern (Aranda-Martín et al., 2022).

Variations in accuracy have also been observed in studies using only faces as targets. For example, Torres-Marín et al. (2017, experiment 1) reported lower accuracy rates for happy, angry and sad expressions in congruent trials compared to incongruent trials. Furthermore, lower accuracy rates with angry faces compared to other expressions have been also noted (Marotta et al., 2022; Torres-Marín et al., 2017). Notably, Torres-Marín et al. (2017, experiment 1) found that gelotophobes had higher error rates than

non-gelotophobes, whereas Marotta et al. (2022) observed that participants with low Autism Spectrum Quotient (AQ) scores made more errors with happy faces than fearful faces.

Considering the findings regarding accuracy and the importance of analysing the temporal dynamics highlighted in previous studies (Hemmerich et al., 2022; Marotta et al., 2019; Román-Caballero et al., 2021b, 2021a; Y. Tanaka et al., 2024, 2025), examining how accuracy varies over reaction time depending on the type of stimuli can be crucial for gaining insight into the dissociation observed between social and non-social stimuli. Therefore, using a distributional approach (Balota & Abrams, 1995; De Jong et al., 1994), employing tools such as the Conditional Accuracy Function (CAF), could reveal when the congruency effects start to diverge between social and non-social stimuli.

In conflict tasks, a distributional approach enables the examination of how experimental manipulations influence the conflict effect across different stages of cognitive processing (Mittelstädt & Miller, 2020; Rousselet et al., 2017). This approach allows for the exploration of the interaction between relevant and irrelevant information, based on a common theoretical framework that points to two parallel processing routes (Banich, 2019; Cohen et al., 1990; De Jong et al., 1994; Ridderinkhof, 2002b, 2002a; Ulrich et al., 2015). These dual-route models propose that task-relevant information is processed through controlled mechanisms, whereas irrelevant information is processed through more automatic, and short living mechanism.

Regarding the CAF, it correlates task execution time with accuracy (Heitz, 2014; Luce, 1991; Wood & Jennings, 1976), offering insights into how response accuracy varies with reaction time (Van Maanen et al., 2019). Typically, with non-social stimuli, accuracy is high across the distribution under congruent conditions but lower for the fastest reaction times under incongruent conditions, increasing as the RTs become longer (e.g. Hübner & Töbel, 2019; Torres-Quesada et al., 2022; Ulrich et al., 2015). Within the dual-route models, the initial boost of irrelevant spatial information by the automatic mechanism (Lu & Proctor, 1995; Torres-Quesada et al., 2022; Ulrich et al., 2015) increases the likelihood of incorrect response in incongruent trials. However, across middle and slower RTs, as the automatic mechanism decreases, the controlled route enhances performance.

To date, no CAF analysis has used gaze targets. However, since modulations typically occur within the fastest responses, analysing this part of the distribution could reveal specific patterns. While electrophysiological evidence suggests that the dissociation in congruency effects between eye-gaze and arrow stimuli occurs at later processing stages (Marotta et al., 2019), earlier stages might also influence this dissociation, especially considering that faces can be distinguished from other stimuli during early processing stages (e.g. Bentin et al., 1996; Nemrodov, 2014). Therefore, this early distinction might modulate the initial boost of the irrelevant spatial information.

Moreover, the temporal-delay and active-suppression hypotheses, which have been used to explain the RCE, were originally developed for the Simon effect (Hommel, 1993; Ridderinkhof, 2002a, 2002b). However, these hypotheses may not apply universally, as different mechanisms might operate across tasks (Funes et al., 2010; Liu et al., 2004; Pratte et al., 2010; Torres-Quesada et al., 2014). Unlike the Simon task, the spatial Stroop involves stimulus–stimulus overlap (direction and location; see table 1 in Kornblum, 1994), which may influence temporal conflict facilitation and inhibition. Integrating our analyses with a spatial Stroop framework will help determine whether the observed effects are due to social components or task-related phenomena.

Thus, in this study, the CAF tool was employed to analyse datasets from studies using the social variant of the spatial Stroop task (Marotta et al., 2018), with the goal of examining how accuracy rates vary over reaction time intervals and uncovering temporal dynamics underlying the dissociation between social and non-social attentional mechanisms. Through this approach, we expect to explore hidden aspects not discernible through mean RT or error rates analysis alone, thereby contributing to a deeper understanding of the interplay between social and non-social information processing.

Method

Studies

The studies included in this analysis are summarized in **Table 1**. Selection criteria focused on methodological similarities, specifically: (1) use of the spatial Stroop Task, (2) comparison between cropped-eyes or faces as social targets and arrows as non-social targets, (3) use of upright faces and (4) the implementation of an explicit discrimination

task. Consequently, we excluded hand-pointing targets (Bonventre & Marotta, 2023; Dalmaso et al., 2023), animal face targets (Ishikawa et al., 2025) and inverted faces (Marotta & Lupiáñez, 2018; Y. Tanaka et al., 2023). From Narganes-Pineda, Chica, et al., (2023), only data from the explicit task with motor responses (experiment 1) were included. We also incorporated studies using only faces to assess potential differences between cropped eyes and complete faces. These studies included emotional expression conditions with five levels: anger, happiness, sadness, fear and neutral (Marotta et al., 2022; Torres-Marín et al., 2017).

Table 1. Studies selected for combined analyses

N	Study	Sample	Target types	Observations
1	Torres-Marín et al. (2017), experiments 1 & 2.	40, 40	Face expressions	
2	Marotta et al. (2018)	35	Arrows vs. Eyes	
3	Marotta & Lupiáñez (2018)	17	Faces: Upright vs. Inverted	Inverted faces were removed
4	Marotta et al. (2019)	27	Arrows vs. Eyes	
5	Hemmerich et al. (2022), experiments 1 & 2	35, 33	Arrows vs. Eyes	
6	Narganes-Pineda et al. (2023), experiment 1	24	Arrows vs. Eyes	
7	Marotta et al. (2022)	36	Face expressions	
8	Bonventre & Marotta (2023), experiments 1 & 2	24, 22	Arrows vs. Hand vs. Eyes	Hand targets were removed
9	Ishikawa et al. (2025), experiments 1 & 3	70, 54	Arrows vs. Cat Face/Robot Face vs. Eyes	Cat face and Robot face targets were removed
10	Y. Tanaka et al. (2023), experiments 1A & 1B	38, 19	Faces: Upright vs. Inverted	Inverted faces were removed
11	Dalmaso et al. (2023)	191[a]	Arrows vs. Hand vs. Face	Hand targets were removed

Note: The samples are separated by a comma when the study has more than one experiment.

[a] One participant was removed due to a higher rate of trials without response (≈ 64%).

It is important to note that several experiments, including those by Hemmerich et al. (2022) and Bonventre and Marotta (2023, experiment 2), presented target types within blocks. However, since this experimental design did not significantly improve the model fit (see Table S1), we excluded it as a relevant factor in the model formula.

Analyses and Design

The analyses were performed using RStudio (Posit Team, 2024), and the script is available on the OSF webpage (see **Data Availability Statement**). We adopted the same cut-off criterion for outliers and data pruning as in most original studies, removing reaction times shorter than 200 ms and longer than 1300 ms for simplicity and comparability, including Dalmaso et al. (2023) who originally used a 3 SD trimming procedure. Both correct and incorrect responses were considered, and the proportion of trials removed is reported in **Table S2**.

CAFs were computed by sorting reaction times from fastest to slowest before being divided into five 20% bins (e.g. Hübner & Töbel, 2019). Accuracy rates were then calculated for each participant within each condition (i.e. target type, congruency and bin) by experiment. We opted to conduct the analyses using 5 bins[1], although as it is typically expected to find modulations within the fastest responses, we performed the same contrast analyses for models MA and MB, which compared social and non-social stimuli, using four 25% bins (see **Appendix S1**).

The datasets were combined to formulate three models (**Table 2**). Models MA and MB included all studies listed in Table 1, covering 16 experiments and 705 participants. We did not consider the emotional expression condition, collapsing the data across target type. In model MA, cropped eyes and faces were categorized as social stimuli, and arrows as non-social stimuli, leading to a three-way design: target type (social vs. non-social), congruency (congruent vs. incongruent) and bin (5 levels). Model MB differentiated faces and cropped eyes resulting in a three-way design: target type (face vs. eyes vs. arrows), congruency (congruent vs. incongruent) and bin (5 levels).

[1] In studies utilizing a distributional approach, the number of bins chosen ranges from 3 to 10 (e.g. Ambrosi et al., 2020; Hübner & Töbel, 2019; Mittelstädt et al., 2022; Van Maanen et al., 2019).

Table 2. Models formulated for CAF analyses

Model	Studies	Nº of Datasets	Design
MA	All the studies listed in Table 1	16	Target Type (social vs. non-social), Congruency (congruent vs. incongruent), Bin (5 levels)
MB	All the studies listed in Table 1	16	Target Type (face vs. eyes vs. arrows), Congruency (congruent vs. incongruent), Bin (5 levels)
MC	Torres-Marín et al. (2017, experiments 1 and 2), Marotta et al. (2022)	3	Expression (anger vs. fear vs. happiness vs. sadness vs. neutral), Congruency (congruent vs. incongruent), Bin (5 levels)

Note: The combined dataset for models MA and MB was the same, except that in MA, we categorized both faces and eyes as social stimuli.

Model MA was based on previous research linking the RCE to eye-gaze processing, regardless of using complete faces or cropped eyes. However, processing whole faces might add extra information. Model MB addresses this, with MA serving as a baseline for comparison. MB could offer new insights, as Hemmerich et al.'s experiment 3 (2022) is the only study directly comparing faces and eyes in this context. Additionally, considering faces as a complex background, this distinction may clarify whether the dissociation results from a background segregation effort.

Model MC aimed to explore differences related to emotional expression conditions at a distributional level by combining data from two studies (i.e. three experiments). The design included: expression (anger vs. fear vs. happiness vs. sadness vs neutral), congruency (congruent vs. incongruent) and bin (5 levels). Additionally, model MC will allow us to observe whether the patterns in model MB are stable using similar studies with face targets only.

Prior to modelling, k-fold cross-validation (Geisser, 1975) assessed dataset suitability for linear mixed modelling (LMM) or beta regression. LMM was chosen based

on mean squared errors (MSEs). We used the lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017) R packages for fitting and testing. The best fit was determined through hierarchical comparisons, using the AIC and BIC criteria, along with the likelihood ratio test (χ^2). Subsequently, the best fitting models were identified (see **Appendix S1**), and significance of main effects and interactions was assessed through several analyses of variance (ANOVA).

For models MA and MB, the arrangement included fixed effects of target type, congruency, bin and their interactions. Given the complex structure of the combined datasets considered grouping and strategies to enhance model fitting (Barr, 2013; Barr et al., 2013; Brauer & Curtin, 2018). Participants were modelled as nested within studies using crossed effects syntax (see implicit nesting in Schielzeth & Nakagawa, 2013). Target type conditions were treated as study-specific features, modelling inter-study variations based on target type, while also acknowledging the specific structure within each study regarding congruency and bin factors. Regarding model MC, due to the similarities between the studies used, the model was simplified to include only a random intercept by participant. The rationale behind the grouping structures is described in **Appendix S1**.

The results presented here are from the best-fitting models (**Table 3**), with a comprehensive account available in **Appendix S1**. Post-hoc contrasts, where applicable, were performed using Tukey's HSD test within the mixed-effects models framework, via the emmeans package in R (Lenth et al., 2025). Reported values represent the estimated marginal means for accuracy (EM Acc), reflecting the model structure. Contrast analyses employed 95% confidence intervals (CIs) and the Kenward-Roger (1997) for estimating the degrees of freedom. Partial eta squared (η_p^2) was estimated using the effectsize R package (Ben-Shachar et al., 2020). Effect sizes (d) for post-hoc contrasts were calculated following Westfall et al. (2014; see also Brysbaert & Stevens, 2018) using the EM Acc.

Table 3. Best-Fitting Models

Model	Target type condition	Formula
MA	Social vs. Non-Social	*Acc ~ TargetType * Congruency * Bin + (1|Study:id) + (1|Study:TargetType) + (1|Study:TargetType:Congruency:Bin)*
MB	Face vs. Eyes vs. Arrows	
MC	Emotional Expressions (anger, fear, happy, neutral, sad)	*Acc ~ Expression * Congruency + Congruency * Bin + (1|Study:id)*

Results and Discussion

The models with the best fit are outlined in Table 3, models MA and MB allowed the three-way interaction, whereas model MC allowed the two-way interactions, between expression and congruency, and between congruency and bin.

Model MA

The analysis of variance (ANOVA) on model MA (**Figure 1**) indicated a significant main effect of target type, $F(1, 22.491) = 7.06$, $p = .0142$, $\eta_p^2 = .239$, with social stimuli associated with lower accuracy (0.958, SE = 0.004) than non-social stimuli (0.975, SE = 0.005). Congruency was also significant, $F(1, 223.383) = 14.81$, $p = .0002$, $\eta_p^2 = .062$, with congruent trials being more accurate (0.972, SE = 0.004) than incongruent trials (0.961, SE = 0.004). Bin main effect was significant too, $F(4, 223.383) = 91.04$, $p < .0001$, $\eta_p^2 = .620$, indicating lower accuracy rates in bin 1 compared to subsequent bins.

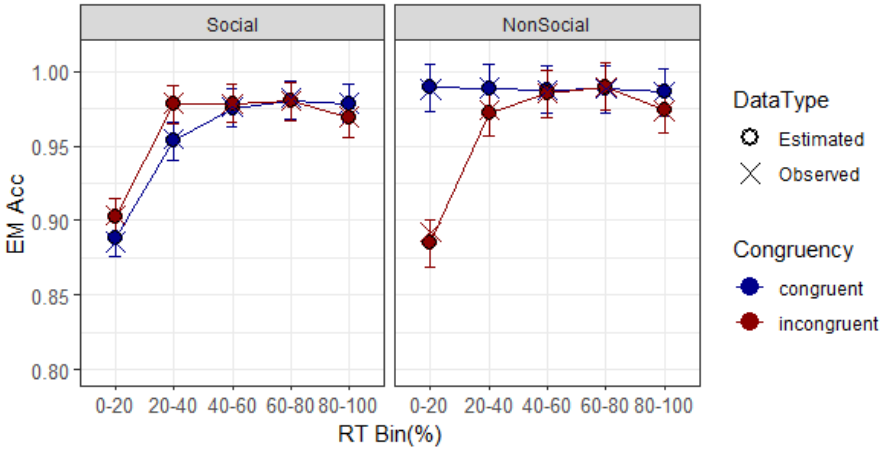

Figure 1. CAF for model *MA*. The y-axis represents the estimated marginal means of accuracy rate (EM Acc). The bars represent the 95% confidence intervals of the EM Acc. Observed values are represented by 'X' and estimated values by 'O'.

The interaction between target type and congruency was significant, $F(1, 223.383) = 38.08$, $p < .0001$, $\eta_p^2 = .146$. In congruent conditions, participants were less accurate with social stimuli ($Acc_{soc} = 0.955$, SE = 0.004) than with non-social ($Acc_{non\text{-}soc} = 0.988$, SE = 0.005), $t(28.8) = -4.90$, $p < .0001$, $d = -.344$. In the incongruent condition no significant differences were observed ($p = .974$). Target type and bin interacted as well, $F(4, 223.383) = 5.84$, $p = .0002$, $\eta_p^2 = .095$, with social targets, in bin 1, being less accurate than non-social targets ($Acc_{soc} = 0.896$, SE = 0.005 vs. $Acc_{non\text{-}soc} = 0.937$, SE = 0.006), $t(27.1) = -5.11$, $p < .0001$, $d = -.435$. The interaction between congruency and bin was also significant, $F(4, 223.383) = 11.68$, $p < .0001$, $\eta_p^2 = .173$, in bin 1, it was observed higher accuracy rate with congruent ($Acc_{cong} = 0.939$, SE = 0.005) than incongruent trials ($Acc_{inc} = 0.894$, SE = 0.005), $t(196) = 7.60$, $p < .0001$, $d = .477$.

Crucially, the three-way interaction was significant, $F(4, 23.383) = 18.29$, $p < .0001$, = .247. Post-hoc contrasts (**Table S5**), revealed significant differences for non-social targets in bin 1, obtaining higher accuracy rate in congruent ($Acc_{cong} = 0.989$, SE = 0.008) than incongruent trials ($Acc_{inc} = 0.885$, SE = 0.008), $t(188) = 11.28$, $p < .0001$, $d = 1.10$. In contrast, in bin 2, social targets showed higher accuracy in incongruent ($Acc_{inc} = 0.871$, SE = 0.006) than congruent trials ($Acc_{cong} = 0.994$, SE = 0.006), $t(208) = -7.27$, $p < .0001$, $d = -.259$. Furthermore, comparisons between bins (**Table S6**), revealed that social stimuli, at bin 1, exhibited lower accuracy rates than subsequent Bins in both, congruent ($t = -12.29$ to -8.65, $p < .0001$, $d = -.944$ to

−.682) and incongruent conditions ($t = -10.29$ to -8.83, $p < .0001$, $d = -.811$ to $-.696$), whereas non-social targets, showed the same pattern only in incongruent trials ($t = -11.34$ to -9.45, $p < .0001$, $d = -1.11$ to $-.922$). Additionally, social stimuli, in the congruent condition, also showed lower accuracy in bin 2 compared to bins 3–5 ($t = -3.64$ to -2.96, $p < .0500$, $d = -.287$ to $-.233$).

Interestingly, as typically observed, modulations were present within the fastest responses of the distribution. With non-social targets, incongruent trials exhibited lower accuracy in the first bin compared to subsequent bins, while accuracy rates remained stable in congruent trials. Additionally, accuracy was significantly higher in congruent than in incongruent trials in the first bin. This common pattern in conflict inhibition research (e.g. Torres-Quesada et al., 2022b; Ulrich et al., 2015; Van Campen et al., 2018; Van Maanen et al., 2019) suggests that the initial boost of irrelevant spatial information, overseen by the automatic mechanism, increased the probability of selecting incorrect responses in incongruent trials (automatic response capture; Torres-Quesada et al., 2022). From the second bin onwards, the automatic mechanism is reduced, leading to increased accuracy in both congruency conditions, as predicted by different models (Hommel, 1993; Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015).

However, with social stimuli, the patterns observed in incongruent trials across bins were also observed in congruent conditions. Moreover, not only that, but congruent trials resulted in even worse performance than incongruent trials within the fastest responses, with significant differences in bin two. The 4-bin model confirmed this pattern, highlighting modulations within the fastest responses (see **Appendix S1**). From a temporal dynamic perspective, this dissociation occurs at earlier processing stages, when task-irrelevant information is still being processed. However, the automatic activation of the response to the irrelevant location would not lead to errors in congruent trials. This implies that additional information within the automatic processing, besides spatial location, interferes with typical patterns, ultimately modulating the congruency effect in terms of accuracy.

Model MB

For model MB (**Figure 2**), the analyses of variance revealed a marginal effect of target type $F(2, 23.38) = 3.40$, $p = .0507$, $\eta_p^2 = .225$, with arrows (0.975, SE = 0.005) showing

higher accuracy rate than face (0.959, SE = 0.006) and eyes targets (0.958, SE = 0.005). The main effect of bin was significant, $F(4, 230.57) = 106.52$, $p < .0001$, $\eta_p^2 = .649$, with lower accuracy rates in bin 1 compared to the subsequent bins and, lower accuracy rate in bin 2 than 4.

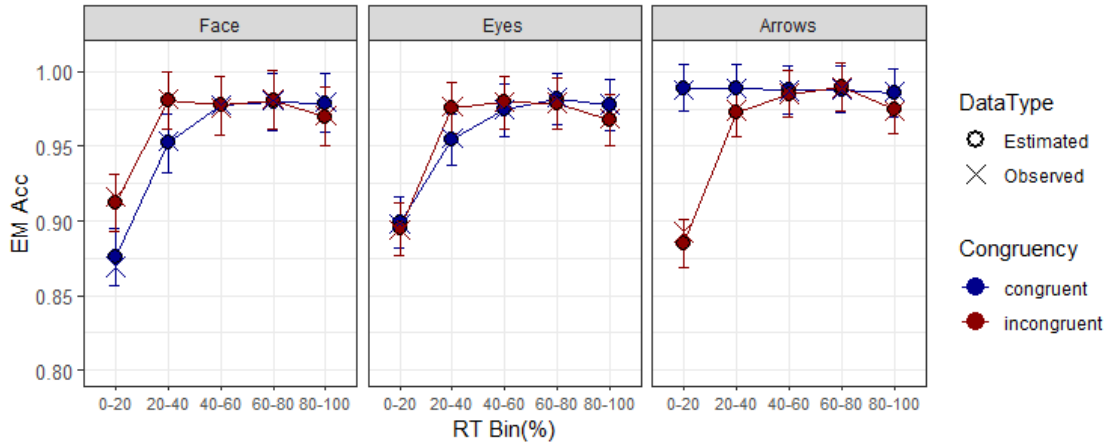

Figure 2. CAF for model *MB*. The y-axis represents the estimated marginal means of accuracy rate (EM Acc). The bars represent the 95% confidence intervals of the EM Acc. Observed values are represented by 'X' and estimated values by 'O'.

The interaction between target type and congruency was significant, $F(2, 230.91) = 19.47$, $p < .0001$, $\eta_p^2 = .144$. In the congruent condition, arrows ($Acc_{arrows} = 0.988$, SE = 0.006) showed higher accuracy than face ($Acc_{face} = 0.953$, SE = 0.007), $t(31.3) = -4.08$, $p < .0010$, $d = -.369$, and eyes targets ($Acc_{eyes} = 0.957$, SE = 0.006), $t(27.1) = -3.98$, $p = .0013$, $d = -.322$. No differences were observed between face and eyes targets, and no differences in the incongruent condition. The interaction between target type and bin was also significant, $F(8, 230.91) = 2.89$, $p = .0043$, $\eta_p^2 = .091$. In bin 1, both social stimuli, face ($Acc_{face} = 0.894$, SE = 0.008) and eyes ($Acc_{eyes} = 0.897$, SE = 0.007) showed lower accuracy rates than arrows ($Acc_{non\text{-}soc} = 0.937$, SE = 0.008), $t(61.4) = -4.17$, $p < .0010$, $d = .452$ & $t(57.1) = -4.30$, $p < .001$, $d = .424$, respectively. Additionally, congruency and bin interacted as well, $F(4, 230.57) = 4.96$, $p = .0007$, $\eta_p^2 = .079$, in bin 1 congruent trials ($Acc_{cong} = 0.921$, SE = 0.005) exhibited higher accuracy rates than incongruent trials ($Acc_{inc} = 0.897$, SE = 0.005), $t(190) = 4.04$, $p < .0001$, $d = .252$.

Importantly, the three-way interaction was again significant, $F(8, 230.91) = 9.56$, $p < .0001$, $\eta_p^2 = .249$. The contrasts analyses (**Table S5**), in bin 1 with face

targets, revealed lower accuracy rate in congruent (Acc_{cong} = 0.876, SE = 0.010) than incongruent trials (Acc_{inc} = 0.912, SE = 0.010), $t(178) = -3.24$, $p = .0014$, $d = -.385$. Conversely, arrow targets exhibited higher accuracy rates in congruent (Acc_{cong} = 0.989, SE = 0.008) than incongruent trials (Acc_{inc} = 0.885, SE = 0.008), $t(180) = 11.08$, $p < .0001$, $d = 1.10$. In bin 2, both, face (Acc_{cong} = 0.952, SE = 0.010 vs. Acc_{inc} = 0.981, SE = 0.010) and eyes targets (Acc_{cong} = 0.954, SE = 0.009 vs. Acc_{inc} = 0.976, SE = 0.009) showed lower accuracy rates in congruent compared to incongruent trials, $t(178) = -2.54$, $p = .0120$, $d = -.302$, and $t(218) = -2.07$, $p = .04$, $d = -.223$, respectively. No differences were observed in the other bins.

On the other hand, the contrasts between bins across congruency levels (**Table S6**), revealed that both face and eyes stimuli, at bin 1, exhibited lower accuracy rates than subsequent bins in both congruent ($t_{face} = -9.18$ to -6.74; $p < .0001$, $d = -1.09$ to $-.802$; $t_{eyes} = -8.07$ to -5.43; $p < .0001$, $d = -.869$ to $-.584$) and incongruent conditions ($t_{face} = -6.07$ to -5.08; $p < .0001$, $d = -.722$ to $-.605$; $t_{eyes} = -11.48$ to -9.90; $p < .0001$, $d = -.890$ to $-.769$), whereas arrows target, showed lower accuracy only in incongruent trials in bin 1 than the other bins ($t_{arrows} = -8.26$ to -7.14; $p < .0001$, $d = -1.10$ to $-.919$).

In model MB, the same patterns were observed as in model MA with non-social stimuli. However, when separating the social stimuli into faces and eyes, the reversion of the congruency effect affected faces earlier, showing reduced accuracy in congruent trials in bins 1 and 2 compared to incongruent trials, while with eyes, this dissociation was observed only in bin 2. This pattern with faces was also observed in the 4-bin model. However, with eyes, although the direction was the same as in the 5-bin model, the dissociation was not significant (see **Appendix S1**). Additionally, for social stimuli, performance was lower in the first bin compared to the rest of the bins in both congruency conditions in the 4-bin and 5-bin models.

Similarly, the modulations occurred within the fastest responses, indicating that additional information beyond spatial location interfered with the usual patterns during early stages of automatic processing. On one hand, it is possible to suggest that faces provide additional social information that facilitates the dissociation from earlier stages, increasing the strength and duration of the effect. This distinction highlights the quick activation of automatic information for faces (other than location), possibly attributed to

their direct recognition (Freiwald et al., 2016; Nemrodov et al., 2014; Watanabe et al., 1999). Conversely, with cropped eyes, this activation might be slightly delayed or reduced, as processing isolated eye stimuli is less familiar. If this is the case, 4-bin model might hide some relevant information since it mixes information between faster and middle responses latencies, giving the same pattern observed as 5-bin model, but without reaching significance (**Figure S2**).

Moreover, considering the temporal sequence of events observed in Marotta et al. (2019), the P1 component exhibited a main effect of congruency without interacting with target type. This suggests that modulations of sensory processing, attributed to attentional orienting (Luck, 1995), may be due to the similar handling of spatially irrelevant information across both stimulus types. Conversely, the subsequent N170 component activation demonstrated a significant difference between eye-gaze and arrow stimuli. Although this early dissociation was not observed in terms of congruency, it might indicate an initial distinction between socially relevant stimuli from non-social stimuli (Bentin et al., 1996; Sagiv & Bentin, 2001). This early distinction could influence subsequent processing stages by introducing new information related to the social nature of the stimuli, such as the *looking vector* dimension (Hemmerich et al., 2022), described as a set of complex social interactions, including gaze direction processing.

On the other hand, based on non-social accounts (Z. Chen et al., 2022; Y. Tanaka et al., 2024, 2025), perceptual factors might modulate the observed patterns. However, perceptual influences alone, without considering eye-gaze, are unlikely to improve performance in incongruent trials compared to congruent ones. This should impact both congruency levels equally, reducing accuracy without showing a reversion.

Alternatively, the dual-stage hypothesis (Y. Tanaka et al., 2024, 2025) suggests the RCE is produced during later processing stages, after segregating directional information from a complex background. According to the activation–suppression hypothesis, the inhibitory process gradually builds up (Ridderinkhof, 2002a, 2002b), making it more efficient for slower responses (e.g. Van Campen et al., 2018). Thus, reversion in accuracy should occur during middle or slower responses and later with faces due to their perceptual complexity. Conversely, if active suppression starts earlier than assumed (Y.

Tanaka et al., 2025), it could modulate performance by interacting with early social information processing.

Model MC

The ANOVA on model MC (**Figure 3**), revealed a main effect of Expression, $F(4, 5667) = 11.26$, $p < .0001$, $\eta^2_p = .008$. Anger condition (0.936, SE = 0.006) showed lower accuracy rate than fear (0.963, SE = 0.006), $t(5667) = -6.34$, $p < .0001$, $d = -.229$, and neutral faces (0.953, SE = 0.006), $t(5667) = -4.01$, $p = .0006$, $d = -.145$. With fear faces, the accuracy was higher than with happy (0.944, SE = 0.006), $t(5667) = 4.36$, $p = .0001$, $d = .158$, and sad (0.946, SE = 0.006) faces, $t(5667) = 3.89$, $p = 0.0010$, $d = .141$. Congruency showed a significant effect, $F(1, 5667) = 97.06$, $p < .0001$, $\eta^2_p = .017$, with incongruent trials (0.961, SE = 0.006) being more accurate than congruent trials (0.935, SE = 0.006). The main effect of bin was also significant, $F(4, 5667) = 171.280$, $p < .0001$, $\eta^2_p = .108$. The patterns were similar for social targets in previous models, being bin 1 less accurate than the subsequent bins. Additionally, it was observed that bin 2 was significantly less accurate than bins 3 and 4.

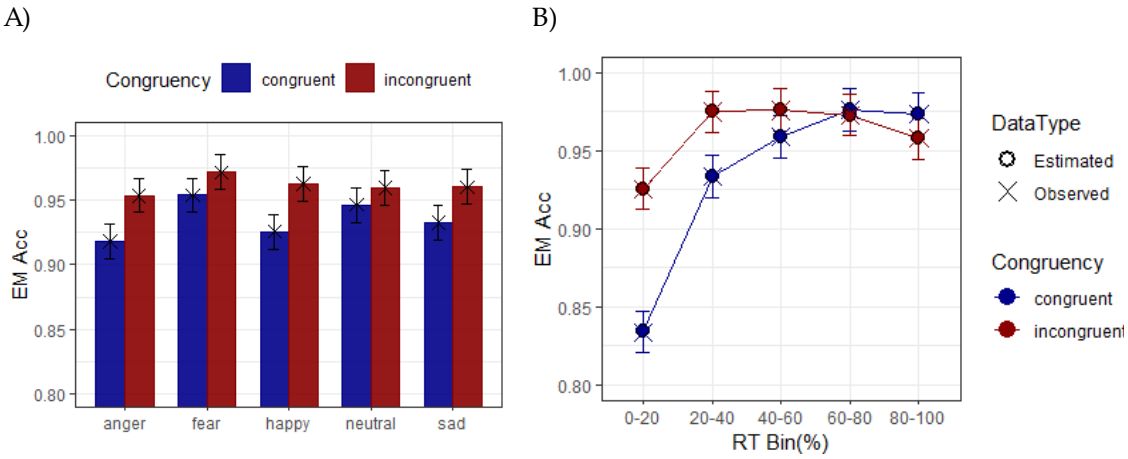

Figure 3. Interactions figures allowed for model MC. A) Bar plot of congruency by expression; B) CAF plot of congruency by Bin. The y-axis represents the estimated marginal accuracy rates (EM Acc), the bars represent the 95% confidence interval of the EM Acc. Observed values are represented by 'X' and estimated values by 'O'.

Model MC showed as significant the two-way interactions, between expression and congruency, $F(4, 5667) = 3.21$, $p = .0121$, $\eta^2_p = .002$, and between congruency and bin, $F(4, 5667) = 50.69$, $p < .0001$, $\eta^2_p = .035$. In the first case, the contrasts analyses between expressions showed that in the congruent condition, anger (0.918, SE = 0.007) were less

accurate than fearful expression (0.954, SE = 0.007), $t(5667) = -5.99$, $p < .0001$, $d = -.306$, and neutral (0.946, SE = 0.007), $t(5667) = -4.73$, $p < .0001$, $d = .242$. In the same direction, happy (0.926, SE = 0.006) showed lower accuracy than neutral, $t(5667) = -3.46$, $p = .0050$, $d = -.177$. Conversely, fear was more accurate than happy, $t(5667) = 4.72$, $p < .0001$, $d = .241$, and sad faces (0.932, SE = 0.007), $t(5667) = 3.60$, $p = .0029$, $d = .184$. In the incongruent condition, only anger (0.954, SE = 0.007) was less accurate than fear (0.971, SE = 0.007), $t(5667) = -2.98$, $p = .0239$, $d = -.153$. In addition, when comparing the congruency levels by expression, in all the cases, the accuracy rate was significantly higher for incongruent than congruent trials ($t = -6.23$ to -2.19, $p < .05$, $d = -.319$ to $-.112$).

With respect to the interaction between congruency and bin, the contrasts across bins, revealed significantly lower accuracy rates with congruent than incongruent trials in bin 1 ($Acc_{cong} = 0.834$, SE = 0.007 vs. $Acc_{inc} = 0.926$, SE = 0.007), $t(5667) = -15.35$, $p < .0001$, $d = -.785$; bin 2 ($Acc_{cong} = 0.933$, SE = 0.007 vs. $Acc_{inc} = 0.975$, SE = 0.007), $t(5667) = -6.96$, $p < .0001$, $d = -.356$; and bin 3 ($Acc_{cong} = 0.959$, SE = 0.007 vs. $Acc_{inc} = 0.976$, SE = 0.007), $t(5667) = -2.90$, $p = .0038$, $d = -.148$. In contrast, in bin 5, a significant higher accuracy rates in congruent than incongruent trials was observed ($Acc_{cong} = 0.973$, SE = 0.007 vs. $Acc_{inc} = 0.958$, SE = 0.007), $t(5667) = 2.61$, $p = .0091$, $d = .134$.

Similarly, the comparisons between bins by congruency revealed similar patterns to those observed in the previous models with social targets. In the congruent condition, the accuracy was significantly lower in bin 1 than the subsequent bins ($t = -23.87$ to -16.67, $p < .0001$, $d = -1.22$ to $-.852$). In addition, in model MC, it was observed also significant differences between bin 2 and the subsequent bins ($t = -7.21$ to -4.27, $p < .0001$, $d = -.369$ to $-.218$), and between bins 3 and 4, $t(5667) = -2.94$, $p = .0273$, $d = -.150$. In the incongruent condition, it was observed lower accuracy rates in bin 1 than the subsequent bins ($t = -8.48$ to -5.41, $p < .0001$, $d = -.433$ to $-.277$). Conversely, it was observed lower accuracy rates in bin 5, when compared with bins 2, $t(5667) = 2.86$, $p = .0346$, $d = .146$ and 3, $t(5667) = 3.069$, $p = .0184$, $d = .157$.

Thus, model MC showed a stable pattern across the distribution within the CAF and the same reversion regarding accuracy for face stimuli as observed in model MB. Interestingly, the decrease in accuracy rates in congruent trials was observed from bin 1

to bin 3 compared to incongruent trials. Moreover, the comparison across bins showed a reduction in accuracy that lasted longer (i.e. bin 3 vs. bin 4). Again, these dissociations were observed within the fastest responses, which are related to earlier stages of processing. Importantly, this model chose methodologically similar studies, whose resemblance allowed a simpler modelling structure with less variance between studies.

Although model MC did not allow for the three-way interaction, and therefore, we did not analyse the expressions' facilitation at a distributional level, the emotional expressions might have added some extra information. Indeed, congruent trials showed modulations that were not apparent in incongruent trials when comparing expressions (**Table S9**). Additionally, we observed a reduction in accuracy for congruent trials within the five emotional expressions, with the neutral expression showing the lowest t-ratio (**Table S7**). These observations suggest that adding extra social information (i.e. emotional expressions) might modulate the patterns observed within the fastest responses in CAFs.

General Discussion

This study aimed to investigate the differences in attentional processing between social and non-social stimuli using a distributional approach, particularly focusing on the Conditional Accuracy Function (CAF; Heitz, 2014; Wood & Jennings, 1976). Accuracy rates were divided into equally sized bins based on reaction time distribution. To achieve this, we combined the datasets from 11 studies (listed in **Table 1**) to fit three models to the data from 705 participants: MA compares social (eyes and faces) with non-social (arrows) targets, MB compares faces, eyes and arrows, and MC assessed variations in accuracy rates based on emotional expressions within face targets.

With non-social targets, our analyses highlighted modulations within the fastest responses, replicating previous results. In models MA and MB, incongruent trials exhibited lower accuracy rates in the first bin compared to subsequent bins, whereas accuracy rates remained stable throughout the distribution in congruent trials. Moreover, accuracy was significantly higher in congruent than in incongruent trials in the first bin. These findings extend previous research reporting more errors in incongruent trials with non-social targets (Bonventre & Marotta, 2023, experiment 1; Ishikawa et al., 2021,

experiment 1; Marotta et al., 2018, 2019), suggesting these differences are primarily evident within the fastest responses. These patterns are consistent with either a passive-decay model (e.g. Hommel, 1993), or an active-inhibition model (e.g. Ridderinkhof, 2002a, 2002b).

However, with social stimuli, the CAFs exhibited three main variations. First, both congruent and incongruent conditions showed reduced accuracy within the fastest responses. Second, congruent (incongruent) trials resulted in worse (better) performance than incongruent (congruent) trials in the initial bins. Third, faces elicited and enhanced these modulations earlier than eyes stimuli. These patterns do not align with the expected facilitation of correct response selection in congruent trials by the automatic mechanism's initial boost (Lu & Proctor, 1995; Torres-Quesada et al., 2022; Ulrich et al., 2015), or the reduced performance in incongruent trials. Overall, these observations suggest that additional information influenced the temporal dynamics of conflict elicitation and resolution during the activation of the automatic mechanism.

The reduced performance for the fastest responses in both congruency levels in model MA could be explained by either social or non-social accounts based on the difficulties in target processing (i.e. the target eyes are embedded and need to be extracted from the face). However, if task-relevant information extraction were the sole cause, model MB should show larger differences in the main effects of target type or the 2 two-way interactions (i.e. target type by congruency, and target type by bin), for faces and eyes, as faces are perceptually more complex and require more time to process. Alternatively, the distinction between socially relevant and non-social stimuli might initially engage attentional resources similarly for social targets, with later differentiation between faces and eyes due to the interaction of perceptual complexity and social-related processing mechanisms.

Regarding the initial distinction of social and non-social stimuli, electrophysiological research has identified early neural indexes, particularly the N170 ERP component in scalp recordings and the N200 ERP component in intracranial recordings (Eimer, 2011; McCarthy, 1999; Rousselet et al., 2014). Faces and eyes typically elicit larger N170 (Rossion & Jacques, 2012), and N200 (Allison et al., 2002) components than other object types. In face detection tasks, heightened sensitivity to contralateral eye

stimuli occurs between the P1 and N170 components, indicating this time window as critical for face processing (Rousselet et al., 2014; Schyns et al., 2003). Moreover, differences have been noted in processing faces, faces without eyes and isolated eyes with both the N170 (e.g. Bentin et al., 1996; Itier & Preston, 2018) and the N200 (e.g. Allison et al., 2002; McCarthy, 1999) components, suggesting different sources principally for 'face-N170' and 'eye-N170', which explains their distinct topographies and developmental courses (Itier et al., 2007; Itier & Preston, 2018; Miki et al., 2015; Nemrodov et al., 2014; Taylor et al., 2004).

After initial stimulus differentiation, interactions between social and non-social information may emerge, influenced by perceptual configuration, task dynamics and the looking vector dimension. Evidence shows that the posterior superior temporal sulcus (pSTS), part of the social perception network (Yang et al., 2015), receives input from primary visual regions sensitive to social stimuli, such as eye-gaze direction (Gobbini & Haxby, 2007; Hoffman & Haxby, 2000). Moreover, faces can be distinguished from other objects without conscious awareness (Morris et al., 2007), suggesting automatic processing. Gaze perception also triggers early, automatic attentional orienting (Brignani et al., 2009; Driver et al., 1999) in occipitoparietal regions (Ulloa et al., 2018). When the looking vector dimension integrates this social information into the automatic mechanism during social trials, it spills over into task-relevant processing. The introduction of gaze direction information in incongruent trials would create a synergistic effect where automatic and controlled processes converge.

The eye-contact hypothesis explains this effect: Participants implicitly perceive the eyes as looking at them in incongruent conditions, enhancing performance (Cañadas & Lupiáñez, 2012; Marotta et al., 2018). Initially, participants process spatially irrelevant information similarly for arrows and gaze. However, in social trials, the nature of the stimuli interferes with spatial information, triggering an eye-contact episode within the automatic mechanism. Simultaneously, the controlled process gathers evidence to guide the decision towards the correct response. In contrast, in congruent trials, no eye-contact episode occurs, and the controlled mechanism does not fully override the automatic mechanism at earlier stages. Variability in the automatic mechanism's strength over time, influenced by cognitive control (Banich, 2019; Soutschek et al., 2013; Ulrich et al., 2015),

explains the pattern in slower responses, where accuracy differences between congruent and incongruent trials diminish.

This dynamic could explain the findings of Narganes-Pineda, Chica, et al. (2023) in implicit tasks where no congruency effect was observed. The looking vector might require the strength of the controlled, task-relevant process to trigger the reversion. Importantly, Narganes-Pineda et al.'s implicit tasks used a Type 3 ensemble, producing a Simon effect. In their experiment 3A (explicit task), participants responded orally to gaze direction, creating no overlap between stimuli and response (i.e. Type 4 ensemble; Kornblum, 1992); yet, a RCE was still observed. This suggests that the RCE might not be entirely stimulus–response related.

Although further exploration is needed to understand how different dimensional overlaps influence the processing of both stimulus types, it is possible that the congruency effect observed in accuracy occurs at different processing levels compared to those facilitating the RCE observed with RT. Y. Tanaka et al. (2025) found that arrows and eye-gaze lead to negative-going delta plots (for characterization of the delta functions, see Speckman et al., 2008), indicating inhibition mechanisms for arrows but the strengthening of the RCE for eye-gaze during middle and slower correct responses, with the reversion observed from the fastest responses only for social stimuli. These differences between the CAFs and delta plots align with the multiple-stage and multiple loci theories (Banich, 2019; De Houwer, 2003; Parris et al., 2022a), suggesting that different processing levels contribute to the overall conflict effect (Viviani, Visalli, Montefinese, et al., 2024).

The idea that control mechanisms adapt to context or task-related conflicts is not new (Funes et al., 2010; Schlaghecken & Martini, 2012; Soutschek et al., 2013). The Stroop effect, for instance, can be generated and inhibited at multiple levels, from stimulus presentation to response execution (Banich, 2019; Torres-Quesada et al., 2022), demonstrating the adaptability of control mechanisms. This adaptability is crucial for complex stimuli like faces, where social information operates across various processes, from perception to higher order cognitive functions (Yang et al., 2015).

Investigating the potential influence of joint attention or joint distraction episodes could provide additional insights. Our primary focus was on automatic mechanisms, as

CAF modulations typically occur within the fastest responses, associated with automatic processing. The eye-contact hypothesis offers a plausible explanation for these patterns. Conversely, joint attention and distraction likely involve higher order cognitive processes (Baron-Cohen, 1994; Hemmerich et al., 2022), which require more time to activate and may affect middle and slower responses modulations that CAFs might not capture.

While the looking vector dimension provides one possible explanation, other factors may also be at play. Testing this hypothesis with targets like tongues, which have been shown to produce a reversion (Y. Tanaka et al., 2024), without triggering an eye-contact episode, could be insightful, given that tongues might still convey social information. The mouth region is important in face processing (e.g. Itier & Preston, 2018; S. Luo et al., 2013), and the tongue has been shown to elicit a cueing effect similar to gaze (e.g. Downing et al., 2004, experiment 1) and plays a role in emotional expression (e.g. Rozin et al., 1994). Therefore, future research should explore alternative explanations by considering perceptual factors and temporal task dynamics, as suggested by non-social theories.

Finally, it is important to acknowledge the study's limitations. The social version of the spatial Stroop task results in minimal errors, which may limit the generalizability of comparisons. Nuanced differences between models MA and MB could arise from study variations, as speed-accuracy trade-off can influence outcomes, particularly conditions emphasizing speed tends to amplify CAF effects in incongruent trials (e.g. Riesel et al., 2019; Wylie et al., 2009). Partitioning the RT distribution into bins has faced criticism for temporal reduction and arbitrary bin selection (Van Leeuwen et al., 2019; Van Maanen et al., 2019). However, this method was specifically designed to analyse accuracy relative to response latencies, considering their distributional characteristics (Luce, 1991; Pachella, 1974; Wood & Jennings, 1976). Given our aims, and the consistent modulations observed within the fastest responses, regardless of bin number (e.g., Hübner & Töbel, 2019; Ulrich et al., 2015; Wolkersdorfer et al., 2020), we found this approach appropriate. Similar modulations have been noted in studies with neurostimulation techniques and diverse populations (e.g. Ambrosi et al., 2020; Van Campen et al., 2018; Van Wouwe et al., 2016).

For a more detailed pattern exploration and hypothesis testing, it is recommended to complement this procedure with others, such as averaging parameter approaches (Rouder & Speckman, 2004). This can be achieved by modelling data using the Drift Diffusion Model (DDM; Ratcliff, 1978; see Myers et al., 2022) or the diffusion model for conflict tasks (DMC; see Ulrich et al., 2015). Future studies should use this approach.

Conclusion

In conclusion, in this study an important dissociation has been observed in attentional processing between social and non-social stimuli, through the use of a distributional approach such as that of the Conditional Accuracy Function (CAF). In particular, the evaluation of accuracy rates across different reaction time bins suggests the existence of relevant differences in response patterns, especially in the early bins. For non-social stimuli such as arrows, congruent trials showed greater accuracy than incongruent ones, for which reduced accuracy was observed on fastest responses, thus confirming the hypothesis that the presence of relevant and irrelevant information generates a conflict that negatively impacts initial performance. On the contrary, for social stimuli, such as faces and eyes, an inverse pattern is observed with congruent trials being less accurate than incongruent ones in the first bins. This dissociation suggests that with social stimuli, not only the automatic capture by the irrelevant target location, but also other automatic processes might modulate decisions in unique ways, perhaps social, unanticipated by traditional models of conflict processing, which would indicate the adaptability of automatic mechanisms to manage the complexity of social information from the initial stages of processing. These findings help to understand how attention and spatial interference mechanisms differ depending on the nature of the stimuli and also highlight the importance of considering the temporal dynamics of attentional processing in future studies.

Supporting Information

The Appendix S1 (Supplemental information for Study 1) can be observed in the link below or in **Appendix A** of the present thesis.

https://bpspsychub.onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1111%2Fbjop.12735&file=bjop12735-sup-0001-AppendixS1.docx

Data Availability Statement

The data, the supplemental material and the script of the analysis that support the findings of this study are openly available in OSF at https://osf.io/twbs3/.

3.2. Study 2. Investigating the gaze-driven reversed congruency effect in the spatial Stroop task: A distributional approach

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Study 2 has been published as:

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Abstract

This study investigated how social (faces and eyes) and non-social (arrows) stimuli modulate attentional orienting in a spatial Stroop task, using a distributional approach. Data from 11 studies ($N = 705$) were analysed through cumulative distribution functions (CDF), delta functions, and polynomial trend analyses. Three models were applied: (1) a reaction time (RT) model comparing social (faces and eyes) vs. non-social stimuli under congruent and incongruent conditions, (2) a delta model assessing conflict effects across quantiles, and (3) a trend model identifying specific delta function patterns. Non-social targets produced a standard congruency effect (SCE), with faster responses in congruent trials but no consistent conflict reduction across the distribution. In contrast, social stimuli exhibited a reversed congruency effect (RCE), with faster responses in incongruent trials, emerging from the second quantile onward and minimal conflict among the fastest responses. Social targets exhibited comparable reaction times in the RT model and similar early delta plot patterns, suggesting shared initial perceptual and attentional mechanisms between faces and eyes. However, faces eventually induced a larger RCE, possibly due to their more complex configuration. These findings highlight distinctive patterns between social and non-social processing in the spatial Stroop task.

Keywords: delta plots, distributional analysis, gaze and arrows, social attention, spatial Stroop

Background

The ongoing debate in social attention research focuses on whether social orienting—paying attention to where others are looking—is driven by general attentional mechanisms related to directional information, like eye-gaze (Cole & Millett, 2019), or by specific social processes involving the interpretation of intentions and mental states (Apperly & Butterfill, 2009). To explore this, and given that arrows and gaze seem to orient attention similarly in standard arrow/gaze cueing paradigms (Chacón-Candia, Román-Caballero, et al., 2023), recent studies have used spatial interference paradigms, such as the spatial Stoop (Cañadas & Lupiáñez, 2012; Jones, 2015; Marotta et al., 2018; Narganes-Pineda, Chica, et al., 2023), to investigate whether social stimuli uniquely activate attentional processes.

In these tasks, stimuli like arrows (non-social) or eyes (social) appear on either side of a central fixation, pointing or looking left or right. Participants respond to the direction of the stimuli while ignoring their spatial location, creating congruent trials (e.g. arrows/gaze directed right on the right side) and incongruent trials (e.g., arrows/gaze directed right on the left side). Arrows typically produce a standard congruency effect (SCE), with faster responses in congruent trials. In contrast, gaze stimuli produce an opposite effect, known as the reversed congruency effect (RCE), where responses are faster in incongruent trials. This phenomenon has been observed in several studies (Cañadas & Lupiáñez, 2012; Dalmaso et al., 2023; Jones, 2015; Marotta et al., 2018; Narganes-Pineda, Chica, et al., 2023), suggesting that gaze triggers specific attentional processes distinct from those activated by other types of stimuli.

The SCE is generally attributed to the asymmetric relationship between stimulus dimensions –specifically, the task-relevant direction and the task-irrelevant spatial location relative to lateralized motor responses (Lu & Proctor, 1995; Viviani, Visalli, Montefinese, et al., 2024). Despite instructions to focus on direction, irrelevant location information consistently influences responses, slowing reaction times (RTs) in incongruent trials. According to Kornblum's (1992) taxonomy, this setup forms a Type 8 ensemble, characterized by three dimensions overlap: between relevant and irrelevant stimulus dimensions, relevant stimulus and response dimensions, and irrelevant stimulus and response dimensions. This requires participants to resolve conflict at various levels – task, stimulus, and response – affecting the overall performance (Banich, 2019; De Houwer, 2003; Parris et al., 2022a; Viviani, Visalli, Montefinese, et al., 2024).

However, the mechanisms driving the interaction between task-relevant and irrelevant information with gaze stimuli, contributing to the RCE, remain under discussion. The reversed effect has led to multiple theories, categorized into social (Cañadas & Lupiáñez, 2012; Edwards et al., 2020; Hemmerich et al., 2022; Marotta et al., 2018) and non-social (Z. Chen et al., 2022; Y. Tanaka et al., 2024, 2025) explanations.

Social theories suggest that gaze processing triggers specific mechanisms that facilitate the RCE. The eye-contact hypothesis (Cañadas & Lupiáñez, 2012; Marotta et al., 2018) proposed that incongruent gaze trials might be implicitly perceived as looking at the participant, leading to faster responses. This is supported by findings indicating that

humans have a tendency to interpret gaze as direct when faced with perceptual uncertainty (Mareschal et al., 2013). However, Narganes-Pineda, Chica, et al., 2023) challenged this, showing that explicit attention to gaze direction is required for the RCE. In their study, when participants had to discriminate the colour of the eyes rather than the direction of gaze, so that task-relevant information changed from direction to colour (i.e., changing the overlapping dimensions), the RCE was not observed.

Edwards et al. (2020) proposed an alternative explanation, suggesting that the RCE might result from a joint attention episode, where incongruent eyes appear to 'look' at the fixation point where participants are focused. However, the reversion was absent in children under 12 (Aranda-Martín et al., 2022), despite joint attention developing by age 4 (Mundy et al., 2007). Hemmerich et al. (2022) later proposed that congruent trials might shift attention away from the task, slowing response times in this condition, thus leading to the RCE. Yet, Aranda-Martín et al. (2023) found no effect on the RCE when using objects or frames to prevent distraction, challenging this hypothesis.

More recently, an integrated framework has been developed that combines general attentional processes with specific social mechanisms, interacting with perceptual features and task dynamics to facilitate or enhance the RCE (Hemmerich et al., 2022; Marotta et al., 2019; Ponce et al., 2025; Román-Caballero et al., 2021a, 2021b). In this view, general attentional processes related to the direction and spatial location of stimuli create similar interference for both arrows and gaze, leading to faster responses in congruent conditions. However, gaze stimuli activate additional processes, incorporating new information that can reverse the typical interference effect, resulting in the RCE.

More specifically, the spatial interference may arise from the interaction of three vectors (Hemmerich et al., 2022): (a) the relevant stimulus direction, (b) its irrelevant spatial location – both common to social and non-social targets – and (c) a 'looking' vector, unique to social stimuli. The interaction between the relevant and irrelevant dimensions would lead to standard congruency for both social and non-social targets. However, the third vector conveys socially meaningful information (Hietanen, 2018), and may be strong enough to override the SCE observed for gaze targets, thereby contributing to the emergence of the RCE (Hemmerich et al., 2022; Ponce et al., 2025; Román-Caballero et al., 2021a, 2021b). Indeed, gaze has been shown to play a

fundamental role in multiple stages of social cognitive processing (Brignani et al., 2009; Mundy, 2018; Yang et al., 2015), facilitating mechanisms related to gaze perception (Kobayashi & Kohshima, 1997), shifts in gaze direction (Gobbini & Haxby, 2007), gaze following (Emery, 2000), and theory-of-mind-related processes (Baron-Cohen, 1994). These processes may account for the strength of the looking vector in the direction where the stimulus is 'looking', which can lead to either slower responses in congruent trials or faster responses in incongruent ones.

This framework is supported by electrophysiological, neuroimaging, and behavioural data. Marotta et al. (2019) found that early event-related components (P1, N1) were similarly affected by congruency in both gaze and arrow stimuli, while later components (N2 and P3) showed opposite patterns. Moreover, although the N170 was not modulated by congruency, differences between arrows and eyes were noted, possibly linked to their nature (Bentin et al., 1996; Nemrodov et al., 2014). An fMRI study by Narganes-Pineda, Paz-Alonso, et al. (2023) revealed similar activations in right parieto-temporo-occipital regions during conflict resolution for both gaze and arrow stimuli, along with distinct activations in the frontal eye field (FEF) and occipital regions.

Behaviourally, Román-Caballero et al. (2021a, 2021b) found that factors reducing the SCE with arrows, such as increased perceptual background complexity[2], which hindered the extraction of task-relevant information, simultaneously amplified the RCE in gaze trials. The need for background segregation before processing directional information – like extracting gaze direction from eyes within a face – created a temporal gap between relevant and irrelevant information. This gap allowed irrelevant information to decay (*temporal-delay* hypothesis; Hommel, 1993), reducing spatial conflict and enhancing the RCE for gaze targets. In addition, a developmental study showed that while a typical SCE was present in children as young as 4 years old and continued through childhood for both gaze and arrows, the RCE specifically observed for gaze stimuli only emerged around age 12 (Aranda-Martín et al., 2022).

[2] The term 'background complexity' is used here as defined in Román-Caballero et al. (2021a, 2021b) and Tanaka et al. (2024, 2025). In this context, a complex perceptual background refers to either coloured geometric rectangular patterns or face stimuli. In both cases, the authors demonstrated that arrows and eyes embedded within such complex backgrounds—geometric or facial—modulate the resulting conflict effect.

Further evidence supports the social interpretation of gaze in producing the reversion. The RCE appears to be influenced by the emotional facial expressions (Jones, 2015; Marotta et al., 2022; Torres-Marín et al., 2017), modulated by social familiarity (Ishikawa et al., 2025), and negatively correlated with social anxiety scores (Ishikawa et al., 2021). While the RCE has been compared with other social cues like pointing hands, the reversion was only observed with gaze targets (Bonventre & Marotta, 2023; Dalmaso et al., 2023). The RCE has also been noted with certain animal faces (Ishikawa et al., 2025), inverted faces (Y. Tanaka et al., 2023), and using oral responses (Narganes-Pineda, Chica, et al., 2023, experiment 3A).

Alternatively, non-social explanations for the RCE focus on perceptual factors (Z. Chen et al., 2022) or task-related effects (Y. Tanaka et al., 2024, 2025). Z. Chen et al. (2022), for instance, found that stimuli with similar perceptual features, whether social or non-social, produced the SCE (although see Cañadas & Lupiáñez, 2012), suggesting that perceptibility influences congruency effects. They also suggested that variations in other studies might result from changes in attentional focus, as described by the zoom lens model (Eriksen & James, 1986).

Y. Tanaka et al. (2024, 2025) introduced the dual-stage hypothesis, challenging the idea that the RCE is exclusively related to gaze mechanisms. After observing the RCE with tongues as directional targets, they built on the findings of Román-Caballero et al. (2021a, 2021b), and the *activation–suppression* hypothesis (Ridderinkhof, 2002a, 2002b) an account that focuses on the temporal dynamics. In the first stage, segregating a target from a complex background (i.e., extracting directional information from eyes within a face) delays the extraction of directional information, allowing the location code to decay (Hommel, 1993). In the second stage, selective attention suppresses irrelevant spatial codes, inhibiting conflict, which ultimately leads to the RCE. Specifically, in congruent conditions – where spatial and directional codes align (e.g., a right-looking gaze in the right visual field) – selective inhibition may suppress the correct spatial code (right), delaying the response. Conversely, in incongruent conditions – where the spatial and directional codes do not align (e.g., a right-directed gaze in the left visual field) – selective inhibition suppresses the incorrect spatial code (left), speeding up the correct responses

(right). For simpler perceptual stimuli like arrows, however, responses occur before response inhibition sets in, making congruent responses faster.

Overall, the RCE appears to arise from a complex interplay between social and non-social components, including perceptual features and temporal-related effects, that modulate processing at multiple levels. This view is consistent with the dimensional overlap model (Kornblum, 1992, 1994) and the multiple stage/loci theories of Stroop interference (Banich, 2019; De Houwer, 2003; Parris et al., 2022), providing a useful framework for assessing these patterns (Viviani, Visalli, Montefinese, et al., 2024). By integrating this framework and building on previous research emphasizing temporal dynamics (Hemmerich et al., 2022; Marotta et al., 2019; Ponce et al., 2025; Román-Caballero et al., 2021a, 2021b; Y. Tanaka et al., 2025), the current exploratory study employs a distributional analysis to deepen our understanding of how social and non-social stimuli affect attentional mechanisms.

In conflict tasks, a distributional approach provides tools to examine how congruency effects evolve over time (Balota & Yap, 2011; Mittelstädt & Miller, 2020; Smith & Ulrich, 2025; Speckman et al., 2008; Torres-Quesada et al., 2022). By segmenting response latency distributions into fastest, intermediate, and slowest responses, we gain clearer insights into underlying mechanisms. This method aligns with the dual-route models, which propose that task-relevant information is processed by controlled mechanisms, while task-irrelevant information is handled by automatic, transient processes (Banich, 2019; Cohen et al., 1990; De Jong et al., 1994; Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015; see also direct and indirect route, for example, C. Luo & Proctor, 2019).

Most distributional research on spatial interference has centred on the Simon and Simon-like tasks, establishing robust predictions and analytical frameworks (Burle et al., 2014; De Jong et al., 1994; Miller & Schwarz, 2021; Mittelstädt & Miller, 2020; Pratte et al., 2010; Proctor et al., 2011; P. Smith & Ulrich, 2025; Ulrich et al., 2015). Given that the spatial Stroop shares key similarities with the Simon task (i.e., irrelevant location-based activation), these same distributional tools offer valuable insights for spatial Stroop research, applied within the framework of social attention.

Thus, the aim of the current study is to investigate the differences in attentional mechanisms involved in resolving spatial conflicts when using social stimuli (gaze) versus non-social stimuli (arrows) in spatial Stroop tasks. Employing a distributional approach, we analyse how congruency effects vary in response latencies, providing deeper insights into the temporal dynamics underlying social and non-social attentional orienting. Additionally, we examine whether the perceptual complexity of the background – such as the difference between full faces and isolated eyes – affects the pattern of the RCE in gaze stimuli.

Previous findings indicate that embedding stimuli within a complex background can modulate spatial interference effects, likely by increasing perceptual demands and hindering the extraction of task-relevant information (Román-Caballero et al., 2021a, 2021b; Y. Tanaka et al., 2024, 2025). This interpretation is consistent with findings from location-based conflict tasks, where interference is modulated by factors, such as reduced visibility (Mittelstädt & Miller, 2020), added conflicting layers (Scerrati et al., 2017), or decreased target discriminability (Ellinghaus et al., 2024). Within this framework, full-face stimuli – compared with isolated eyes – are thought to introduce greater visual complexity by embedding directional cues within a richer social and perceptual context (Ponce et al., 2025; Román-Caballero et al., 2021a; Y. Tanaka et al., 2024). To investigate how these differences shape the time course of conflict resolution, we employed both the cumulative distribution function (CDF) and the delta function.

The CDF enables exploration of RT behaviour for congruent and incongruent trials at different distribution points (Ambrosi et al., 2019; Leber et al., 2013; Ulrich et al., 2015), allowing comparisons between social and non-social targets, as well as between faces and eyes (within social targets). Typically, when analysing mean RTs, social targets elicit slower RTs than non-social targets (Bonventre & Marotta, 2023; Dalmaso et al., 2023; Ishikawa et al., 2021). Moreover, based on prior research suggesting that faces require greater target–background segregation demands (Ponce et al., 2025; Román-Caballero et al., 2021a, 2021b; Y. Tanaka et al., 2024, 2025), we expect faces to elicit slower RTs than isolated eyes, reflecting the increased complexity involved in extracting directional information.

In addition, the delta function – derived from the CDF – can reveal how conflict effects vary across the RT distribution (De Jong et al., 1994; Pratte et al., 2010; Schwarz & Miller, 2012; P. Smith & Ulrich, 2025; Speckman et al., 2008). Delta functions represent quantile differences in RT distributions between congruent and incongruent conditions, often visualized in delta plots. These plots can be further analysed using slope or polynomial contrast analyses to assess their shape (Burle et al., 2014; Debey et al., 2015; Pratte, 2021). Typically, a less positive slope indicates more efficient inhibitory control – whether through stronger suppression of irrelevant information or additional resource allocation for target processing (Hübner et al., 2010; Mittelstädt, Mackenzie, et al., 2023; Ridderinkhof, 2002a, 2002b; van Campen et al., 2014). However, and not mutually exclusive, other research suggests that the slope of the delta plots may also reflect the relative speed of processing irrelevant versus relevant information (Mackenzie et al., 2022; Miller & Schwarz, 2021). Based on Y. Tanaka et al. (2025), we expect negative-going delta plots, reflecting across quantiles a reduction of the SCE for non-social targets and a larger RCE for social targets. Furthermore, if background segregation is essential for the reversion (as posited in the first stage of the dual-stage hypothesis), it is crucial to examine whether faces and eyes diverge in the fastest responses, before the reversed effect becomes more pronounced.

Ultimately, by examining RT distributions through both the CDF and delta function, this study provides a general perspective on how social and non-social stimuli impact attentional processes across different stages of cognitive processing, considering their underlying temporal dynamics.

Method

Studies

The studies included in this analysis are summarized in **Table 1**, covering 16 experiments and 705 participants. To ensure comparability, we applied the same selection criteria as Ponce et al. (2025): (1) use of the spatial Stroop task, (2) comparison of cropped-eyes or faces as social targets with arrows as non-social targets, (3) use of upright faces, and (4) implementation of an explicit discrimination task. Consequently, we excluded hand-pointing targets (Bonventre & Marotta, 2023; Dalmaso et al., 2023), animal faces

(Ishikawa et al., 2025), and inverted faces (Marotta & Lupiáñez, 2018; Y. Tanaka et al., 2023). From Narganes-Pineda, Chica, et al. (2023), only data from the explicit task with motor responses (experiment 1) were included. Additionally, we did not consider the emotional expression condition (Marotta et al., 2022; Torres-Marín et al., 2017), collapsing the data across target type.

Table 1. Studies selected for combined analyses

N	Study	Sample	Target types	Observations
1	Torres-Marín et al. (2017), experiments 1 & 2.	40, 40	Face expressions	Data were collapsed across target types
2	Marotta et al. (2018)	35	Arrows vs. Eyes	
3	Marotta & Lupiáñez (2018)	17	Faces: Upright vs. Inverted	Inverted faces were removed
4	Marotta et al. (2019)	27	Arrows vs. Eyes	
5	Hemmerich et al. (2022), experiments 1 & 2	35, 33	Arrows vs. Eyes	
6	Narganes-Pineda, Chica et al. (2023), experiment 1	24	Arrows vs. Eyes	
7	Marotta et al. (2022)	36	Face expressions	Data were collapsed across target types
8	Bonventre & Marotta (2023), experiments 1 & 2	24, 22	Arrows vs. Hand vs. Eyes	Hand targets were removed
9	Ishikawa et al. (2025), experiments 1 & 3	70, 54	Arrows vs. Cat Face/Robot Face vs. Eyes	Cat face and Robot face targets were removed
10	Y. Tanaka et al. (2023), experiments 1A & 1B	38, 19	Faces: Upright vs. Inverted	Inverted faces were removed
11	Dalmaso et al. (2023)	191	Arrows vs. Hand vs. Face	Hand targets were removed

Note: The samples are separated by a comma when the study has more than one experiment.

Although some parameters varied across experiments, all the included studies shared the same ensemble type (Type 8) according to Kornblum's dimensional overlap taxonomy (Kornblum, 1992, 1994). In each task, participants were required to discriminate the direction of lateralized targets (faces, eyes, or arrows) while ignoring

their spatial location, using left/right motor responses. This structural similarity aligns with the dual-route models used in our interpretation of the results. To account for residual methodological heterogeneity, we used mixed-effects models with a nested random structure that treated participants as nested within studies and modelled target type as study-specific. This approach allows study-level variability to be controlled statistically while preserving comparability in the aggregated analysis.

Analyses and design

The analyses were conducted using RStudio (Team, 2024), with the script and datasets available on the OSF webpage (see data availability statement). To ensure consistency and comparability, we used the same cut-off criteria for outliers and data pruning as in most original studies, excluding RTs shorter than 200 ms and longer than 1300 ms. We also repeated the analyses with non-trimmed dataset (i.e., excluding only trials without responses), which revealed that the overall patterns remained stable for social targets (see **Appendix S1**). One participant from Dalmaso et al. (2023) was excluded due to a high rate of non-responses (≈64%). Only correct responses were analysed, with the proportion of removed trials detailed in (**Table S1**).

The distributional analyses utilized the CDF and the delta function, employing the quantile-averaging technique (De Jong et al., 1994; Ratcliff, 1979). The R quantile function was used (Grange, 2016; Mackenzie & Dudschig, 2021) to obtain five quantiles estimates at .1, .3, .5, .7, and .9 for each participant and experimental condition. Including five quantiles increases sensitivity to potential changes across the distribution, with the .5 quantile corresponding to the median (Grange, 2016; Hübner & Töbel, 2019; Smith et al., 2004). We applied the Type 8 quantile estimator as recommended by Hyndman and Fan (1996) to generate the CDF dataset for fitting the RT model. The delta function was derived by subtracting congruent quantiles from their corresponding incongruent ones, creating the delta dataset for fitting the delta model. The delta plot (**Figure 2**) was constructed by plotting delta function estimates against RT model estimates by quantile and target type.

Both RT and delta models were used to compare faces, eyes, and arrows, enabling us to examine distinctions between social and non-social stimuli and to explore

differences between social targets. The RT model compared response latencies based on congruency across the distribution, using a three-way design: target type (face vs. eyes vs. arrows), congruency (congruent vs. incongruent), and quantile (five levels). The delta model analysed conflict effects across the distribution with a two-way design: target type (face vs. eyes vs. arrows) and quantile (five levels). To further explore the consistency of the delta function patterns, analyses were repeated with four and 10 data points (quartile and decile models), with results detailed in **Appendix S1**. Additionally, to examine the trend of the delta plot, we employed an orthogonal polynomial contrast (Grant, 1956) by fitting the Trend model to the delta dataset – a method shown to better quantify the shape of the delta plot (see Burle et al., 2014; Pratte, 2021).

A linear mixed modelling (LMM) approach was applied using the lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017) R packages for model fitting and testing. The best-fitting RT and delta models were identified through a stepwise procedure, which involved backward elimination of non-significant effects (see **Table S2**). The RT model included target type, congruency, quantile (QQ), and their interactions as fixed effects. The delta model included target type, quantile, and their interaction. The Trend model used target type and mean RTs as predictors. Random effect structures accounted for study-specific characteristics and complex nested data using crossed effects syntax (Schielzeth & Nakagawa, 2013). Participants were modelled as nested within studies, with target type treated as a study-specific feature, considering also the distributional characteristics of each study as in Ponce et al. (2025). The rationale for these grouping structures is provided in **Appendix S1**.

Contrast analyses were performed using Tukey's HSD test within the mixed-effects framework via the emmeans package in R (Lenth et al., 2025) for pairwise comparisons. One-sample comparisons against zero were also conducted on delta estimated values to determine whether a conflict effect was elicited at specific data points using Bonferroni's adjustment. Reported values represent estimated marginal means for reaction times (EMM-RT) and delta values (EMM-Δ) from the RT and delta models, respectively. Polynomial contrast analysis, comparing linear and quadratic coefficients, was performed using the emtrends function in emmeans, also with Bonferroni's adjustment. All contrast analyses employed 95% confidence intervals (CIs) and the

Kenward–Roger method (Kenward & Roger, 1997) for estimating the degrees of freedom. Partial eta squared (η_p^2) was estimated using the effectsize R package (Ben-Shachar et al., 2020), and effect sizes (d) for post-hoc contrasts were calculated following Westfall et al. (2014; see also Brysbaert & Stevens, 2018), using the EMM-RT and EMM-Δ values.

Results and Discussion

The fitted models are summarized in **Table 2**. Stepwise analysis of the RT model revealed significant two-way interactions between target type and congruency, target type and quantile, and congruency and quantile, leading to contrast analyses for these specific interactions. The delta model showed a significant interaction between target type and quantile. Unlike the other models, the Trend model, which was used for polynomial contrast to analyse the trend from the delta dataset, did not undergo stepwise analysis.

Table 2. Fitted models employed within the analyses.

Model	Formula
RT	*RT ~ TargetType * Congruency + TargetType * QQ + Congruency * QQ + (1|Study:id) + (1|Study:TargetType) + (1|Study:TargetType:Congruency:QQ)*
Delta	*delta ~ TargetType * QQ + (1|Study:id) + (1|Study:TargetType) + (1|Study:TargetType:QQ)*
Trend	*delta ~ TargetType * poly(meanRT, degree = 2) + (1|Study:id) + (1|Study:TargetType) + (1|Study:TargetType:meanRT)*

RT model

The analysis of variance (ANOVA) on RT model showed a main effect of target type, $F(2, 20.59) = 31.92$, $p < .0001$, $\eta_p^2 = .756$, with participants responding faster to arrows (508 ms, SE = 10.8) than to faces (610 ms, SE = 12.9) and eyes (615 ms, SE = 11.4), and no significant difference between face and eye targets. The main effect of congruency, $F(1, 232.91) = 16.44$, $p < .0001$, $\eta_p^2 = .066$, showed faster RTs in incongruent trials compared with congruent ones. The quantile main effect, $F(4, 232.91) = 2665.18$, $p < .0001$, $\eta_p^2 = .979$, indicated a consistent increase in RTs across quantiles.

The interaction between target type and congruency was significant, $F(2, 233.22) = 147.68$, $p < .0001$, $\eta_p^2 = .559$. Contrast analyses, showed differences between faces and arrows in congruent, $t(24.0) = 7.77$, $p < .0001$, $d = 1.438$, and incongruent conditions, $t(24.0) = 4.22$, $p = .0010$, $d = .781$. Similarly, significant differences were found between eyes and arrows in congruent, $t(19.2) = 9.00$, $p < .0001$, $d = 1.464$, and incongruent trials, $t(19.2) = 5.38$, $p < .0001$, $d = .875$. Both social targets led to slower RTs in both congruency conditions compared with arrows (**Table 3**). In contrast, no significant differences were observed between faces and eyes either in congruent or in incongruent trials.

Table 3. Estimated marginal means of reaction times by target type and congruency.

Target type	Congruent		Incongruent	
	EMM-RT	**95% CIs**	**EMM-RT**	**95% CIs**
Face	624 (13.0)	[597, 651]	595 (13.0)	[569, 622]
Eyes	627 (11.5)	[603, 650]	604 (11.5)	[580, 628]
Arrows	493 (10.9)	[470, 515]	524 (10.9)	[502, 546]

Note. The column EMM-RT shows the estimated marginal means of RT in milliseconds, with the standard error in parentheses. The 95% confidence interval for the EMM-RT are provided in brackets.

Within the same interaction, contrast analyses between congruency levels by target type showed the reversion for both, face targets, $t(190) = 9.26$, $p < .0001$, $d = .314$, and eyes targets, $t(227) = 8.05$, $p < .0001$, $d = .246$, where incongruent trials were faster than congruent trials (**Figure 1a**). In contrast, arrows exhibited the SCE, $t(192) = -12.16$, $p < .0001$, $d = -.343$, with faster responses in congruent compared with incongruent trials.

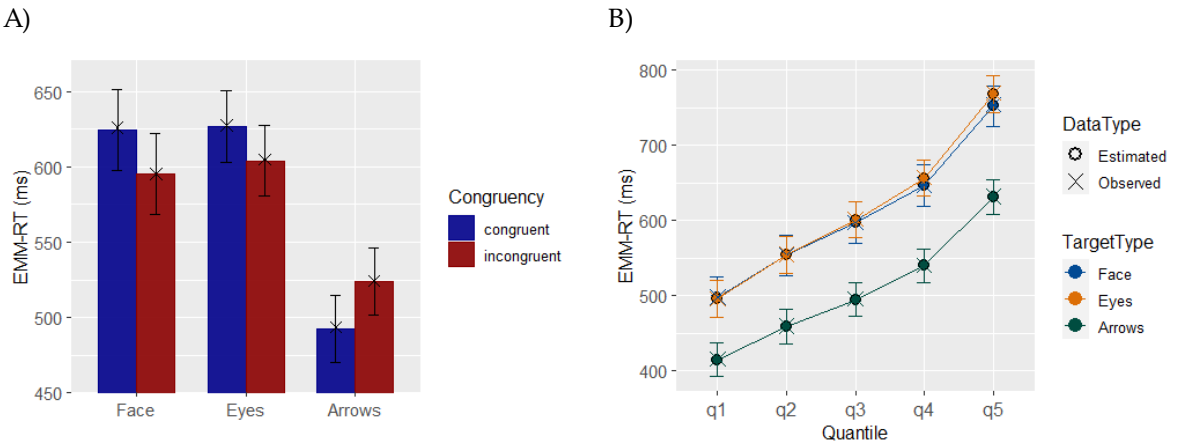

Figure 1. Interactions in the RT model. A) Bar plot of congruency by target type; B) CDF plot of estimated marginal means of reaction time (EMM-RT) by quantile at *.1, .3, .5, .7, .9* probabilities. The bars represent the 95% confidence interval for the EMM-RT. Observed values are denoted by 'X' and estimated values by 'O'.

The interaction between target type and quantile (**Figure 1b**) was also significant, $F(8, 233.22) = 12.86$, $p < .0001$, $\eta_p^2 = .306$. Contrast analyses by quantile revealed no differences between face and eyes targets across the distribution. Moreover, both face and eye stimuli were significantly slower than arrows at all five quantile points, although the difference increased across quantiles.

The RT model replicates the SCE with arrows and the RCE with face and eye targets observed in previous studies (Chacón-Candia et al., 2024; Ishikawa et al., 2021; Marotta et al., 2018; Y. Tanaka et al., 2023). Additionally, non-social targets elicited faster RTs than social targets, consistent with prior findings (Bonventre & Marotta, 2023; Dalmaso et al., 2023; Ishikawa et al., 2021; Narganes-Pineda, Chica, et al., 2023). This difference between social and non-social targets also grew larger with increasing quantiles (**Figure 1b**).

However, no significant differences were found between face and eye targets, despite the expectation that faces would consistently yield slower RTs due to their more complex perceptual configuration. This pattern across quantiles suggests that faces do not necessarily require additional processing time. Moreover, these equivalent response times between faces and isolated eyes appear to be unaffected by congruency, indicating that congruent (incongruent) faces elicit responses at equivalent times that congruent (incongruent) eyes. If background complexity influenced RTs, faces would consistently

show slower responses across studies, either in terms of congruency effects or overall RTs. Alternatively, if both social targets share similar components – whether in terms of social significance or perceptual processing mechanisms related to extracting relevant information (see **General Discussion**) – conflict inhibition processes may integrate these components with spatial information codes, leading to similar attentional orienting patterns, in a way that results in equivalent RTs.

Delta model and Trend Analyses

The ANOVA on the delta model revealed a main effect of target type, $F(2, 24.72) = 97.43$, $p < .0001$, $\eta_p^2 = .887$. Both social targets differed significantly from arrows, which exhibited a positive congruency effect ($\Delta_{arrows} = 30.8$, SE = 3.39). Additionally, no significant difference was found between face and eyes ($p = .3519$), with both showing negative delta values ($\Delta_{face} = -29.7$, SE = 4.08 & $\Delta_{eyes} = -22.0$, SE = 3.62). There was also a main effect of quantile, $F(4, 92.34) = 23.08$, $p < .0001$, $\eta_p^2 = .500$.

The model revealed a significant two-way interaction between target type and quantile, $F(8, 92.01) = 3.99$, $p = .0004$, $\eta_p^2 = .258$. Importantly, this interaction was also found in the quartile and decile models and when employing the non-trimmed dataset, with differences between social and non-social targets remaining consistent across the distribution. Notably, no differences were observed in the fastest responses between faces and eyes; the only significant difference emerged at the fifth quantile, $t(50.7) = -3.26$, $p = .0060$, $d = -.400$, with faces showing a more negative congruency effect (**Figure 2**). Similar patterns were observed in the quartile and decile models, with marginal differences between social targets at the fourth quartile and significant effects at the ninth and tenth deciles, respectively (see **Appendix S1**).

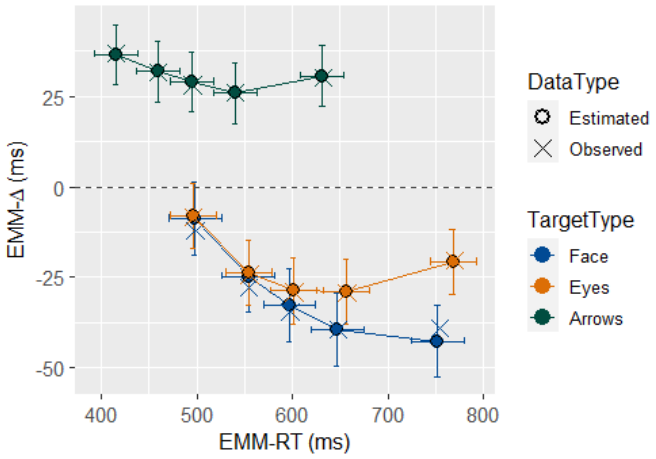

Figure 2. Delta plots derived from the delta model. The y-axis displays the estimated marginal means of the delta function (EMM-Δ), with bars representing the 95% confidence intervals. The x-axis shows the estimated marginal means of reaction time (EMM-RT) at *.1, .3, .5, .7, .9* probabilities, with the bars representing the 95% confidence interval for the EMM-RT. Observed values are represented by 'X' and estimated values by 'O'.

Contrast analyses against zero by quantile showed significant SCEs for arrows across all quantiles ($t = 6.23$ to 8.82, $p < .0001$, $d = .473$ to .669), a finding that held in both quartile and decile models – indicating a SCE from the fastest to the slowest responses. In contrast, the RCE for social targets emerged from the second quantile onward, with faces yielding *t*-values from −8.57 to −4.97, $p < .0001$, $d = -.781$ to −.452, and eyes from −6.40 to −4.60, $p < .0001$, $d = -.528$ to −.380. In the quartile model, the RCE was evident from the first quartile for both eyes and faces, although this effect was partly dependent on the probability chosen to construct the dataset (see quartile-B model in **Appendix S1**). The decile model, however, showed significant reversion from decile 2 to 10, with no conflict effect observed at decile one. Overall, yielding similar and equivalent conflict effect sizes for both social targets within the fastest and intermediate response latencies.

Polynomial trend analysis revealed a significant negative linear coefficient for faces (coeff. = −.200 [−.23, −.17], $p < .0001$), and for eyes (coeff. = − .092 [−.13, −.06], $p < .0001$), along with a significant positive quadratic term for all target types: faces (coeff. = − .0003 [.0002, .0005], $p < .0001$), eyes (coeff. = − .0003 [.0002, .0004], $p < .0001$), and arrows (coeff. = − .0003 [.0002, .0004], $p < .0001$). This pattern remained consistent in the non-trimmed dataset for social targets, whereas both coefficients were non-significant for arrows (see **Table S3** in the **Supplemental Material**). The quartile model consistently

showed negative linear and positive quadratic terms for all targets, and the decile model confirmed negative linear terms for faces and eyes along with significant quadratic terms across all three targets. These findings suggest that trend analysis for arrows is sensitive to the trimming procedure and quantile selection, while faces and eyes maintain a stable trend.

Additionally, faces displayed a significantly more negative linear coefficient than eyes, diff. = −0.108, SE = 0.0197, $t(5714) = -5.48$, $p < .0001$, and arrows, diff. = −0.192, SE = 0.0159, $t(5755) = -12.11$, $p < .0001$. Eyes also showed a more negative slope than arrows, diff. = −0.085, SE = 0.0166, $t(5552) = -5.09$, $p < .0001$. These differences were stable across the different models (see **Appendix S1**). These results indicate that, as response latencies increase, the negative trend becomes more pronounced for face targets.

The delta model showed a stable SCE for arrows across the distribution, regardless of the number of quantiles used. However, as indicated by the trend analysis, the reduction in conflict effects was not uniform across quantiles, differing from the typical patterns observed in other location-based conflict tasks, such as the Simon or Simon-like tasks (De Jong et al., 1994; C. Luo & Proctor, 2017, 2019). Similarly, Y. Tanaka et al. (2025) found that the SCE with arrows persisted throughout the distribution in experiment 1, but in the combined and supplemental analyses, no significant spatial Stroop effect appeared in the last data point. However, comparisons between points 3 and 4 (called bins by the author) did not reach significance, suggesting stabilization in the reduction of the conflict effect.

In spatial Stroop tasks, the reduction in the congruency effects is often less pronounced and seems to affect the fastest and middle response latencies (Castel et al., 2007, Figure 2; Juncos-Rabadán et al., 2008, see *t*-tests performed with the youngest group).[3] This contrasts with the visual Simon effect, where conflict reduction can extend to the slowest responses (C. Luo & Proctor, 2019, experiment 1A) and sometimes even eliminates the conflict effect at slower RTs (Mittelstädt & Miller, 2020, experiment 1;

[3] In Castel et al. (2007) and Juncos-Rabadán et al. (2008), tasks involving a Type-8 ensemble are described in terms of a Simon effect. For consistency, however, we refer to them here as spatial Stroop tasks, as they employ lateralized arrows with motor responses—thus creating overlap among relevant direction and irrelevant physical position, as well as among direction and motor response, and location and motor response (Kornblum, 1992; Viviani, Visalli, Montefinese, et al., 2024). These tasks match those used in the current analyses.

Zhong et al., 2020). The similarities in faster responses may stem from both tasks eliciting conflict related to the irrelevant spatial location of the stimuli. Conversely, the differences may reflect distinct underlying mechanisms – possibly due to additional dimensional overlaps between task-relevant and -irrelevant stimulus features, as well as between task-relevant information and response in the spatial Stroop, which are absent in the Simon task (Kornblum, 1992; Viviani, Visalli, Montefinese, et al., 2024). Previous research has shown that these task-related differences yield distinct conflict patterns likely due to variations in their underlying temporal dynamic, ultimately modulating delta plot shapes (Egner, 2008; Funes et al., 2010; Liu et al., 2004; C. Luo & Proctor, 2017, 2019; Pratte et al., 2010; Scerrati et al., 2017; P. Smith & Ulrich, 2025; Torres-Quesada et al., 2014, 2022; Ulrich et al., 2015).

For social targets, the RCE was observed from the second quantile onward (or from the second decile in the decile model) and from the first quartile in the quartile model – consistent with Y. Tanaka et al.'s (2025) findings on gaze. The different patterns observed in the fastest responses between the quartile model and other models seem to depend on the chosen quantile probabilities (see **Appendix S1**). Nonetheless, consistent findings between models indicate that within the fastest responses, the conflict effect is minimal and does not reach significance. This supports the idea that spatial interference does diminish before the RCE can emerge (Román-Caballero et al., 2021a, 2021b; Y. Tanaka et al., 2024, 2025).

Moreover, differences between faces and eyes were not evident until the slowest responses, which have implications for background segregation. If extracting relevant information from the background is necessary for the RCE, it should influence the fastest or middle response latencies—particularly for faces, which have greater perceptual complexity. Alternatively, background segregation may be executed similarly for both social stimuli, potentially reflecting processes linked to gaze perception rather than strict segregation mechanisms (Kobayashi & Kohshima, 1997; Stephenson et al., 2021). Some evidence highlights the crucial role of the eyes in early face processing (Itier & Preston, 2018; Nemrodov et al., 2014; Nemrodov & Itier, 2011), which could facilitate the extraction of task-relevant information at similar times for faces and isolated eyes before attentional orienting is triggered.

Following the initial reduction of the conflict effect, the reversion emerges and then amplifies until reaching a peak, as indicated by the trend analysis (i.e., quadratic trend). This increase in the reversion effect is reflected by a negative-going delta plot (**Figure 2**). A similar pattern was reported by Y. Tanaka et al. (2025, combined analysis), who found an initial negative-going delta plot followed by a reduction in the RCE when examining eye-gaze stimuli (although see results of the experiment 1).

Negative-going delta plots commonly appear in visual Simon tasks (Ambrosi et al., 2019; De Jong et al., 1994; Miles & Proctor, 2012; Ridderinkhof, 2002a; van Campen et al., 2014) and can even reveal reversed conflict effects during slower responses – particularly under manipulations of motor response compatibility (De Jong et al., 1994) or proportion compatibility (Ridderinkhof, 2002a, 2002b; with Flanker task see Hübner & Töbel, 2019).

When irrelevant information is spatial (i.e., stimuli are presented on the left or right), these patterns are typically explained by active control models, which propose that the irrelevant dimension is actively suppressed by a flexible control mechanism whose onset and strength may vary based on task characteristics and individual differences (Hübner & Töbel, 2019; Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015; van Campen et al., 2014). Alternatively, passive-decay models assume that irrelevant information simply fades over time (Hommel, 1993; Mittelstädt & Miller, 2020; Pratte et al., 2010; van den Wildenberg et al., 2010). However, under both accounts, conflict is typically stronger in faster responses and then diminishes over time, resulting in negative-going delta plots (or inverted U-shaped delta plots, for example, Davranche & McMorris, 2009; Ulrich et al., 2015). Hence, in addition to reflecting the strength and onset of control mechanisms, the shape of the delta plot may also indicate the relative speed at which task-irrelevant versus task-relevant information is processed (Mackenzie et al., 2022; Miller & Schwarz, 2021; Mittelstädt, Mackenzie, et al., 2023).

Overall, this interplay among control mechanisms, processing speed, and the dimensional overlap characteristic of the spatial Stroop likely modulates both the observed reversion and the delta plot trend. As mentioned previously, these task-related factors might produce outcomes that resemble the Simon effect but also introduce unique patterns. For instance, reversed conflict effects with non-social targets have been observed

(Z. Chen et al., 2022, experiment 2; Román-Caballero et al., 2021a, experiment 1), along with negative-going delta plots in which the reversion emerged during slower responses (Y. Tanaka et al., 2025) – a phenomenon linked to increased difficulty in extracting relevant information (see the dual-stage hypothesis; Y. Tanaka et al., 2024, 2025). In contrast, when gaze stimuli are used, the reversion appears as early as the fastest responses (i.e., quantile two) and remains larger at mid-range response times, suggesting that the RCE develops earlier for social stimuli, potentially due to their social relevance or distinctive perceptual features.

General Discussion

This study investigated attentional orienting differences between social and non-social stimuli, focusing on faces and eyes as social targets. A distributional approach was used, employing CDF analyses and distributional and trend analyses of delta functions. Data from 11 studies (**Table 1**) were combined, yielding a sample of 705 participants. Three models were applied: the RT model (from the CDF dataset) to compare RT distributions by target type and congruency; the delta model to examine conflict effects across quantiles; and the Trend model to identify specific trends in delta functions using orthogonal polynomial contrast analyses.

In summary, non-social stimuli consistently produce SCE, with quicker responses in congruent trials across all quantiles. In contrast, social stimuli such as faces and eyes displayed an RCE, where faster responses are observed in incongruent trials starting from the second quantile onward, following a quadratic trend. This early dissociation suggests a more complex processing dynamic for social stimuli, possibly due to their inherent complexity and the social cognitive mechanisms they engage.

On the other hand, the absence of differences between faces and eyes in the CDF results and in the fastest and middle-range responses of the delta function suggests that both social targets undergo similar early processing in terms of overall RTs and conflict inhibition patterns. This early phase of processing is likely influenced by the eye region, which plays a crucial role in how faces are processed (Bentin et al., 1996; Itier et al., 2007; Itier & Preston, 2018; Nemrodov & Itier, 2011; Rousselet et al., 2014). The distinct white sclera of human eyes enhances the detection of small gaze shifts (Calder et al., 2008;

Kobayashi & Kohshima, 1997, 2001), allowing for rapid attentional capture by both eyes and full faces, making their processing at this stage equivalent. Prior research suggests that attention is automatically drawn to biologically and socially significant stimuli, such as faces (Eastwood et al., 2001; Ro et al., 2007), enhancing attentional capture (Langton et al., 2008; Morrisey et al., 2019; Theeuwes & Van der Stigchel, 2006).

Within the dual-route framework, this process aligns with theories like the activation–suppression race model (Miller & Schwarz, 2021), which suggests a competition between the suppression of irrelevant activation and the identification of relevant information prior the selection and motor execution of a response. In a scenario where eye-gaze and face stimuli are processed, this means that if relevant information is processed faster and/or if the influence of irrelevant spatial information decays or is suppressed by the time directional cues trigger a response, its impact is diminished. This could explain the absence of significant differences in early responses between eye and face stimuli.

However, these early perceptual and attentional mechanisms do not fully account for the subsequent increase in the RCE or for the more pronounced effect observed for faces compared with eyes in slower responses.

From a social processing perspective, intermediate and slower responses might allow higher order social processes – such as eye contact (Cañadas & Lupiáñez, 2012; Marotta et al., 2018; Ponce et al., 2025), joint attention (Edwards et al., 2020), or joint distraction episodes (Hemmerich et al., 2022). Full faces which inherently contain more complex and nuanced information, like emotional expressions, intentions, gender, or dominance (Bernstein et al., 2007; Haxby et al., 2000; Leopold & Rhodes, 2010), may therefore facilitate a more prolonged RCE. If facial stimuli engage attention for longer periods than simpler cues like isolated eyes (Langton et al., 2008; Theeuwes & Van der Stigchel, 2006), the temporal window for the emergence of a 'looking vector' – a socially meaningful attentional signal that operates beyond basic directional cueing (Hemmerich et al., 2022) – increases. This extended engagement may amplify the peak of the reversion, as reflected in the delta plot, when compared with the effects observed with cropped-eyes. Indeed, prior studies using full-face cues with additional social features – such as emotional expression (Marotta et al., 2022; Y. Tanaka et al., 2023; Torres-Marín et

al., 2017) or social familiarity (Ishikawa et al., 2025) – have shown notable modulations of spatial conflict effects.

These findings suggest that the 'looking vector' may support privileged access to socially meaningful spatial information, facilitating enhanced attentional selection and faster responses towards the spatial location that the stimulus appears to be 'looking at' (Hemmerich et al., 2022). Originally introduced within the framework of joint distraction, the looking vector may also reflect joint attention episodes or implicit eye contact, depending on task context and stimulus configuration. Instead of treating these theoretical accounts as mutually exclusive, we interpret the looking vector as a flexible mechanism supporting several higher order social processes. This perspective aligns with models of gaze perception and social cognition that emphasize dynamic interactions between bottom-up and top-down systems (Hadders-Algra, 2022; Yang et al., 2015), which ultimately shape attentional dynamics over time (Stephenson et al., 2021).

Alternatively, social and task-related accounts may not represent competing explanations. Instead, the mechanisms proposed by both perspectives could operate together, dynamically contributing to the emergence and modulation of the RCE (Ponce et al., 2025; Román-Caballero et al., 2021a, 2021b; Y. Tanaka et al., 2024, 2025). Social features may enhance attentional engagement and the salience of directional cues (Román-Caballero et al., 2021a, 2021b; Y. Tanaka et al., 2024), while the structural characteristics of the spatial Stroop task determine when and how interference arises and is resolved (Ponce et al., 2025; Y. Tanaka et al., 2025).

Building on this interplay, we suggest that social processes might be modulated by the inherent structure of the spatial Stroop task at both stimulus and response levels (Kornblum, 1992, 1994; Viviani, Visalli, Finos, et al., 2024; Viviani, Visalli, Montefinese, et al., 2024). At the stimulus level, stimulus–stimulus (S–S) overlap arises when both relevant and irrelevant dimensions contain spatial information (C. Luo & Proctor, 2017, 2019; Torres-Quesada et al., 2022). For instance, eyes on the left side of the screen looking right produce a congruency effect tied to processes at the stimulus identification stage (Kornblum, 1992, 1994), reflecting a different time window for conflict processing compared with response level conflict (Frühholz et al., 2011), and suggesting a perceptual basis (Kornblum et al., 1999; Scerrati et al., 2017). As discussed in previous paragraphs,

early extraction of gaze information during stimulus identification stage may account for the delta plot pattern observed in the fastest responses.

In addition, the spatial Stroop involves stimulus–response (S–R) overlap, where both relevant and irrelevant stimulus dimensions influence the response. Research comparing S–S and S–R overlap points to distinct and independent mechanisms for handling conflicting information and inhibiting responses, potentially affecting different segments of the response latency distribution (Correa et al., 2010; Egner, 2008; Frühholz et al., 2011; Li et al., 2014; C. Luo & Proctor, 2017, 2019; Scerrati et al., 2017; Torres-Quesada et al., 2014, 2022). In particular, when task-irrelevant information overlaps with the response dimension, S–R conflict is thought to emerge during the response selection stage through the superimposition of relevant and irrelevant information processing and a response capture mechanism favouring the irrelevant information (De Jong et al., 1994; Lu & Proctor, 1995; Scerrati et al., 2017; Torres-Quesada et al., 2022; van Campen et al., 2014, 2018). Interestingly, it has been observed that conflict processing and inhibition can persist into response initiation and motor execution (Miller & Roüast, 2016; Scorolli et al., 2015; Servant et al., 2016). This is particularly relevant given that the spatial Stroop also involves overlapping between task-relevant information and the response dimension, which might contribute further to the resultant conflict effect (Zhang & Kornblum, 1998), by modulating response capture.

Within this S–R framework, dual-route models propose that an automatic route processes stimulus onset independently of the S–R mapping instructions, with response capture reflecting the susceptibility of selecting a response based on irrelevant spatial location (Cohen et al., 1990; De Jong et al., 1994; Hommel, 1993; Hübner et al., 2010; Miller & Schwarz, 2021; Mittelstädt, Mackenzie, et al., 2023; Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015; van Campen et al., 2014). For example, when a stimulus appears on the right side, it automatically triggers a rightward response and right-hand motor preparation (Torres-Quesada et al., 2022; van Campen et al., 2014, 2018), even if the correct response is to the left. At the response selection stage, this automatic activation is held in check by the controlled route (Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015; van Campen et al., 2014). When relevant and irrelevant information conflict (i.e., incongruent trials), additional

control processes are engaged to resolve the discrepancy, leading to slower RTs and increased error rates.

The overall impact of information carried via the automatic route (i.e., irrelevant spatial location) depends on both the onset timing and suppression strength of task-irrelevant activation (Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015), as well as any enhancement of task-relevant processing (Mittelstädt, Mackenzie, et al., 2023; Mittelstädt & Miller, 2020; Servant et al., 2016). These suppression mechanisms are essential for counteracting response capture (Ridderinkhof, 2002a, 2002b; van Campen et al., 2014, 2018), which – as noted – is triggered by the irrelevant spatial location. Importantly, this interaction between automatic and controlled processes can be further modulated by specific stimulus features (Ellinghaus et al., 2024; Mittelstädt & Miller, 2020), leading to different delta function patterns.

In this regard, social targets may further modulate the balance between automatic activation and control mechanisms. Prior work suggests that social stimuli may recruit additional resources – either due to their social salience (Hemmerich et al., 2022; Marotta et al., 2018, 2019; Román-Caballero et al., 2021a, 2021b) or their perceptual complexity, which may hinder to some extent gaze direction extraction (Y. Tanaka et al., 2024, 2025). These factors may ultimately influence the strength of response capture and/or the demands on control mechanisms. For instance, conditional accuracy function (CAF) analyses (Ponce et al., 2025) showed that social targets elicit distinctive response capture mechanisms. Specifically, these targets not only produce a response capture towards the irrelevant information – reflected by lower accuracy in the first bin compared with later bins in incongruent trials (for a similar interpretation of response capture with CAF, see van Campen et al., 2014) – but also reverse the pattern typically observed with non-social targets (Torres-Quesada et al., 2022; van Campen et al., 2014, 2018) with even lower accuracy for congruent trials in the initial bins. Notably, this CAF reversion was more apparent for faces than isolated eyes, and the effect was amplified when faces with emotional expressions were included (see model MB and MC in Ponce et al., 2025).

This suggests that relevant information from social targets may also be processed via the automatic route to some extent and/or that control mechanisms are engaged more

rapidly, either by inhibiting irrelevant information earlier (Ponce et al., 2025; Y. Tanaka et al., 2025), or by enhancing the processing of relevant information.

If social targets require stronger inhibition for successful response selection (Y. Tanaka et al., 2024, 2025), and if such inhibition takes time to develop (Ridderinkhof, 2002a, 2002b), this would primarily impact middle-range and slower responses, where the peak of the RCE was observed. This would model the dynamic of the RCE, for instance, following a similar description of Tanaka's second stage (Y. Tanaka et al., 2024, 2025), in incongruent trials, the incorrect response (and its motor preparation) may already be inhibited by the time the relevant information is processed, allowing the correct response to proceed faster (and accurately). Conversely, in congruent trials the automatic response capture remains inhibited until the controlled mechanism selects the correct response; once selected, any remaining inhibition must dissipate before motor execution, leading to slower overall RTs (while the inhibition is not decreased the error rates increase).

Moreover, face stimuli, with their greater perceptual complexity compared with isolated eyes, may further intensify this mechanism – as supported by the CAF results in Ponce et al. (2025) – resulting in a more pronounced RCE, particularly evident in the slower responses of the delta function. The stronger automatic activation elicited by full-face stimuli would demand not only earlier onset but also greater strength of inhibition. If this inhibition persists even after the correct response is selected, it could lead to longer delays before execution in congruent trials, thereby amplifying the RCE, while still maintaining a similar overall delta shape compared with eyes (as indicated by the trend analysis). These dynamics align with variability observed in location-based conflict tasks (C. Luo & Proctor, 2019; Mittelstädt, Mackenzie, et al., 2023; Ridderinkhof, 2002a, 2002b) and in diffusion model parameters (C. Luo & Proctor, 2020; Ulrich et al., 2015), particularly with respect to the amplitude and onset timing of the automatic mechanism.

For consideration, this interpretation of the delta function patterns builds on previous findings showing that both active control mechanisms and processing speed (De Jong et al., 1994; Mackenzie et al., 2022; Mittelstädt, Mackenzie, et al., 2023; Mittelstädt & Miller, 2020; Ridderinkhof, 2002a, 2002b), along with dimensional overlap (C. Luo & Proctor, 2017, 2019; Scerrati et al., 2017; Torres-Quesada et al., 2014, 2022),

contribute to shaping delta plot dynamics. This view is consistent with the idea that the Stroop effect involves multiple loci and stages of processing (Augustinova et al., 2018; De Houwer, 2003; Parris et al., 2022a; Viviani, Visalli, Finos, et al., 2024; Viviani, Visalli, Montefinese, et al., 2024; Zhang & Kornblum, 1998).

Nonetheless, it is important to acknowledge that the current methods do not permit a direct mapping of delta patterns onto more specific discrete cognitive stages. While delta functions provide informative insights into temporal dynamics – and have been widely used to support dual-route models in conflict tasks (Ambrosi et al., 2019; Balota & Yap, 2011; Hübner & Töbel, 2019; Miller & Schwarz, 2021; Mittelstädt & Miller, 2020; Smith & Ulrich, 2025) – their interpretative resolution remains limited. For more detailed hypothesis testing, we recommend complementing this approach with parameter estimation methods (Rouder & Speckman, 2004), such as computational modelling using the diffusion model for conflict tasks (DMC; Ulrich et al., 2015).

Additionally, we develop this proposal under the assumption that these patterns reflect a mechanism specific to gaze processing within the spatial Stroop task (Ponce et al., 2025; Y. Tanaka et al., 2025). Nevertheless, Y. Tanaka et al. (2024) observed a reversion with tongues embedded in faces by the second data point in a four-point delta function (Y. Tanaka et al., 2024, Supplemental Material), although no conflict effect was elicited in the first point of the distribution – unlike the pattern seen with gaze (first experiment and combined analysis). Similarly, our results revealed the RCE emerging as early as the second quantile in a five-point delta function, suggesting that gaze might trigger reversion sooner, following a different initial trajectory. However, because tongues were also embedded in faces, they likely conveyed face-related information at early stages, eliciting similar patterns. The mouth region plays a key role in face processing (Itier & Preston, 2018; S. Luo et al., 2013), and the tongue can cue attention similarly to gaze (Downing et al., 2004, experiment 1) or express emotion (Rozin et al., 1994), potentially creating comparable patterns.

On the other hand, the RCE has also been observed with non-social targets (Z. Chen et al., 2022, experiment 2; Román-Caballero et al., 2021a, experiment 1; Y. Tanaka et al., 2025), indicating that it is not exclusive to gaze mechanisms. Further exploration of subtle differences in temporal conflict elicitation and inhibition may reveal unique

dynamics attributable to gaze versus other types of stimuli. Such investigations could help distinguish gaze-driven patterns from those shaped by general task dynamics or perceptual factors.

Conclusion

This study reveals that social and non-social stimuli elicit distinct temporal dynamics in spatial conflict resolution. While arrows produced a SCE across the distribution, gaze stimuli elicited a RCE from the early quantiles of the distribution onward – highlighting their unique influence on attentional control. Among social stimuli, although faces are perceptually more complex than isolated eyes, both produced comparable RTs and similar delta function patterns in early responses – suggesting that gaze direction is extracted at similar stages, likely due to shared attention to the eye region. However, delta plots diverged in slower responses in which faces produced a larger RCE than eyes, indicating that either their social nature or added perceptual complexity amplifies response-related control mechanisms over time. These findings highlight how social stimuli modulate conflict resolution not only through initial gaze extraction but also via late-stage processes, offering new insight into how gaze cues differ from arrows in shaping spatial attention under conflict.

Supporting Information

The Appendix S1 (Supplemental Materials for Study 2) can be found in the link below or in **Appendix B** of the present thesis.
https://bpspsychub.onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1111%2Fbjop.70004&file=bjop70004-sup-0001-AppendixS1.docx

Data Availability Statement

The data, the **Appendix S1**, and the script of the analysis that support the findings of this study are openly available in OSF at **https://osf.io/twbs3/**.

3.3. Study 3. Is the Reversed Congruency Effect Observed with Gaze due to its Social Nature? Analysis of Non-Social Stimuli with Similar Asymmetrical Contrast Features of Eye-gaze Stimuli

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Study 3 is currently under review. The preprint is available at:

Ponce, R., Castellanelli, G., Marotta, A., Román-Caballero, R., Chacón-Candia, J. A., Casagrande, M., & Lupiáñez, J. (2025, October 1). Is the Reversed Congruency Effect Observed with Gaze due to its Social Nature? Analysis of Non-Social Stimuli with Similar Asymmetrical Contrast Features of Eye-Gaze Stimuli. https://doi.org/10.31234/osf.io/d9nw4_v1*

* Part of the data was included in the master's thesis of the second author, Greta Castellanelli

Abstract

The reversed congruency effect (RCE), typically observed with gaze stimuli, reflects slower and less accurate responses to congruent than incongruent trials, in contrast to the standard congruency effect (SCE; faster for congruent than incongruent trials) observed with arrows. This phenomenon has been interpreted as evidence that gaze engages unique social and perceptual mechanisms. The present study examined whether the RCE could also be elicited with non-social stimuli designed to mimic the asymmetric contrast between iris and sclera. Across two preregistered experiments, we manipulated the contrast polarity of arrow targets: in gaze-similar arrows, a darker arrowhead and lighter tail paralleled the iris-sclera configuration, whereas in gaze-opposite arrows this relation was reversed. We also varied perceptual context by embedding stimuli in complex backgrounds. Both manipulations influenced response speed and accuracy, eliciting the SCE, with complex backgrounds producing slower, less accurate performance and reduced SCEs. Distributional analyses further revealed modulations of early response dynamics but no evidence of an RCE. Target-specific effects also emerged, with gaze-similar arrows harder to process yet eliciting smaller SCEs than gaze-opposite arrows. These findings suggest that contrast polarity and perceptual complexity alone are insufficient to reproduce gaze-induced RCEs, underscoring the unique role of gaze in spatial conflict resolution.

Key words: Reversed congruency effect, Spatial Stroop, Gaze and Arrows, Distributional analyses, Cognitive control

Public significance statements: This study examined whether the unique effects of gaze on attention could be reproduced with non-social stimuli that mimic the contrast between the dark iris and the white sclera of the eye. Across two preregistered experiments, we manipulated the contrast polarity of arrow targets and increased visual complexity by embedding them in patterned backgrounds. Although both manipulations influenced performance, they did not reproduce the "reversed congruency effect" typically observed with gaze. This suggests that gaze cues engage additional processes that go beyond visual complexity, highlighting their special role in guiding attention and behavior. Understanding this unique contribution of gaze to spatial conflict has broader

implications for theories of attention and for explaining why gaze plays such a central role in human communication.

Introduction

Gaze is one of the most fundamental cues in social cognition, conveying critical information about others' attention, intentions, and emotional states. Across development and cultures, humans exhibit a remarkable sensitivity to gaze direction (Emery, 2000; Farroni et al., 2004) supporting key processes such as joint attention, theory of mind, and social learning (Baron-Cohen et al., 1994; Mundy, 2018; Stephenson et al., 2021).

In attentional research, gaze cues are often compared to non-social directional stimuli such as arrows (e.g., Kingstone et al., 2003), which share certain functional features but lack inherent social meaning. Both types of cues effectively reorient attention in variants of the Posner cueing paradigm (Posner, 1980), typically producing comparable cueing effects (i.e., faster responses to validly than invalidly cued targets), despite their different nature (for a review, see Chacón-Candia et al., 2023a). This functional similarity has led some researchers to propose that both gaze and arrow cues engage common, domain-general attentional processes (Cole & Millett, 2019; Santiesteban et al., 2014).

However, it remains debated whether these similarities reflect shared mechanisms or whether gaze additionally engage social-cognitive processes such as mental state attribution (Apperly & Butterfill, 2009; Shepherd, 2010).

Evidence from modified cueing paradigms (Chacón-Candia et al., 2020, 2023b; Marotta et al., 2012) and spatial interference tasks (Cañadas & Lupiáñez, 2012; Marotta et al., 2018) suggests that the traditional Posner paradigm is not able to capture social-domain-specific processes underlying attentional orienting.

To address this limitation, researchers have increasingly adopted spatial interference paradigms (Lu & Proctor, 1995; Viviani et al., 2024), especially gaze adaptations of the spatial Stroop task (Marotta et al., 2018), first introduced by Cañadas and Lupiáñez (2012).

In this task, participants respond to the direction indicated by a lateralized target (e.g., a face looking left or rightward) while ignoring its spatial location. Trials are

congruent when the target's direction matches its location on the screen (e.g., a face looking left presented on the left), and incongruent when they conflict (e.g., a face looking right presented on the left). Notably, Cañadas and Lupiáñez (2012) observed that gaze stimuli produced a reversed congruency effect (RCE), with faster responses on incongruent trials, which is opposite to the usual effect elicited by arrows, that is, a standard congruency effect (SCE), with faster responses on congruent trials (Marotta et al., 2018).

This dissociation has been replicated across various labs and task variations (e.g., Edwards et al., 2020; Ishikawa et al., 2021; Jones, 2015), with the RCE consistently observed for different types of gaze stimuli, ranging from isolated eyes to full faces, and even including some domestic animals (but not other animals) or inverted faces (Hemmerich et al., 2022; Ishikawa et al., 2024; Tanaka et al., 2023). In contrast, the effect is typically absent with other directional cues such as pointing hands or words with spatial meaning (Bonventre & Marotta, 2023; Dalmaso et al., 2023; Hemmerich et al., 2022). Moreover, the RCE is modulated by factors such as emotional expression (Torres-Marín et al., 2017; Marotta et al., 2022), stimulus familiarity (Ishikawa et al., 2024), and social anxiety (Ishikawa et al., 2021).

These findings initially inspired socially based interpretations of the RCE. One proposal suggested that inward-directed gaze on incongruent trials elicits an episode of direct eye contact, facilitating faster responses (Cañadas & Lupiáñez, 2012; Marotta et al., 2018). Another suggested that incongruent gaze enhance *joint attention* by aligning the participants' focus of attention with the direction of gaze (Edwards et al., 2020), both focusing at the fixation point. Alternatively, the *joint distraction* hypothesis posits that congruent gaze (i.e., outward looking gaze, as a right looking gaze presented to the right) may misdirect attention away from the task-relevant location, thereby slowing responses when the participant has to reorient back to the task space (Hemmerich et al., 2022).

However, several findings challenge these social interpretations. Narganes-Pineda et al. (2022) showed that explicit processing of gaze direction is required to elicit the RCE, inconsistent with a purely automatic eye-contact account. Developmental studies by Aranda-Martín et al. (2022) showed that children under 12 exhibit an SCE with gaze, similar to that observed with arrows. It is not until adolescence that participants (12 years

old and older) begin to show the RCE with gaze. This developmental trajectory is inconsistent with the early emergence of joint attention mechanisms, typically observed around the age of four (Mundy et al., 2007). Furthermore, attempts to reduce distraction in congruent trials by adding contextual elements (e.g., a colored frame) did not modulate the RCE (Aranda-Martín et al., 2023), undermining the joint distraction hypothesis.

A more integrative framework combines domain-general and domain-specific mechanisms. Hemmerich et al. (2022) proposed that the RCE results from the interaction of three "vectors": the task-relevant direction and the task-irrelevant spatial location (both shared by social and non-social targets), and a uniquely "looking vector" tied to the perceived gaze direction. This framework suggests that gaze-specific processes can override the SCE, producing the overall reversed pattern observed (Hemmerich et al., 2022; Ponce et al., 2025a).

Neurophysiological evidence supports this view, showing early overlap in spatial conflict processing between gaze and arrows, but later divergences consistent with social-cognitive involment (Marotta et al., 2019; Narganes-Pineda et al., 2023).

From a behavioral standpoint, Román-Caballero et al. (2021a, 2021b) demonstrated that embedding stimuli in complex, face-like backgrounds, simulating the perceptual complexity of faces, reduced the SCE observed with arrows, while enhancing the RCE observed with gaze was enhanced when gaze stimuli were used instead of cropped eyes. They attributed this to the *temporal-delay* hypothesis by Hommel (1993): increased background complexity delays extraction of directional information, allowing the spatial code to decay. For gaze, once the SCE is reduced, an additional gaze-related component reverses the typical pattern. These findings suggest that the SCE must be reduced in order for the RCE to emerge, or that any factor reducing the shared SCE increases the RCE.

However, some findings challenge the notion that the RCE is specific to gaze stimuli. Tanaka et al. (2024) observed an RCE using tongue stimuli, targets unlikely to trigger gaze related processes, which led to the proposal of the dual-stage account grounded in the *activation-suppression* hypothesis (Ridderinkhof, 2002a, 2002b). In this view, delayed access to the direction code (Román-Caballero et al., 2021a) allows the

spatial code to decay (Hommel, 1993), after which inhibition acts on any remaining conflict. On congruent trials, inhibition may suppress the correct response as it overlaps with the irrelevant code, resulting in a delay. In contrast, on incongruent trials, inhibition facilitates performance by suppressing the incorrect, location-based response, leaving the appropriate response free to proceed. With highly discriminable stimuli like arrows, conflict resolves too quickly for this reversal to emerge, but with more difficult stimuli, even non-social targets may elicit RCEs.

The extent to which perceptual difficulty alone can produce the reversed effect remains debated. Non-social stimuli have occasionally elicited reversed effects, but their magnitude tends to be smaller and less consistent than those observed with gaze targets (Román-Caballero et al., 2021a; Tanaka et al., 2025). Moreover, recent findings suggest that conflict effects elicited by social and non-social stimuli may also differ in their temporal dynamics, as revealed by distributional analyses (Ponce et al., 2025a, 2025b; Tanaka et al., 2025), indicating that gaze stimuli may elicit distinct temporal patterns.

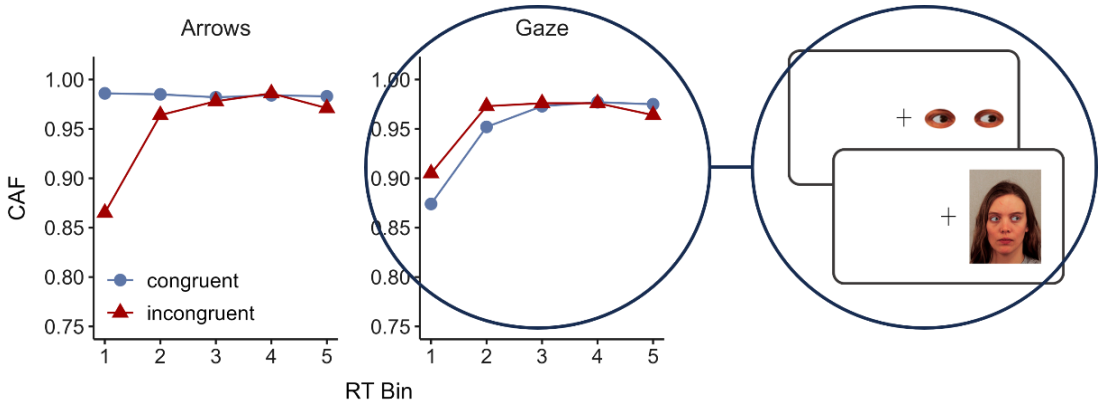
Importantly, Conditional Accuracy Function (CAF) analyses, which examines accuracy as a function of response speed (Heitz, 2014), revealed a dissociation within the fastest responses (Ponce et al., 2025a). With non-social stimuli, early responses show reduced accuracy for incongruent trials, converging over time (Torres-Quesada et al., 2022; van Campen et al., 2014, 2018). With gaze stimuli, however, two notable deviations appear: (1) reduced accuracy for both congruent and incongruent trials among the fastest responses, and (2), more errors for congruent than incongruent trials (see **Figure 1**).

Typical CAF pattern has been attributed to response capture (Salzer et al., 2019; van Campen et al., 2014, 2018; van Maanen et al., 2018), grounded in the dual-route framework, where task-relevant information is processed through controlled mechanisms, and task-irrelevant codes through a transient automatic route (Banich, 2019; Braver, 2012; Cohen et al., 1990; De Jong et al., 1994; Luo & Proctor, 2019; Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015). Response capture reflects early activation based on spatial location, information carried by the automatic route. This activation occurs prior to the onset of inhibitory mechanisms (Burle et al., 2016; Mittelstadt et al., 2023b; Ridderinkhof, 2002a, 2002b), the decay of the irrelevant spatial code (Hommel, 1993), or both (White et al., 2018).

With gaze, reduced accuracy on fast congruent trials suggests interference from additional factors beyond location-based responses (Ponce et al., 2025a). This cannot be explained by automatic allocation of attention toward gaze direction (Cañadas & Lupiáñez, 2012; Marotta et al., 2018; Edwards et al., 2020; Hemmerich et al., 2022), since congruent gaze should facilitate correct response selection. Instead, the interference likely arises from the perceptual configuration inherent to gaze stimuli. What needs to be explained is why fast responses to congruent gaze (e.g., a right looking gaze presented to the right) results in pressing the opposite, incorrect key (i.e., left key in this example) in a substantial proportion of trials.

Figure 1

CAFs for Arrow and Gaze Stimuli (adapted from Ponce et al., 2025a), and Illustration of the Iris–Sclera Contrast



Note. On the left, CAFs for arrows show the typical pattern: reduced accuracy for incongruent trials (red) compared to congruent trials (blue-purple) among the fastest responses. In contrast, gaze stimuli show reduced accuracy for both conditions, with congruent trials dropping even further. On the right, examples of gaze-congruent trials are shown for isolated eyes and faces. In these cases, the white sclera points toward the incorrect response, which may account for the accuracy drop observed in the CAF.

The only possibility is that the RCE may not arise from high-level social cognitive processing, but rather from low-level perceptual features specific to gaze, which would add some additional conflict. Gaze acts both as a socially relevant cue and as a directional signal (Chacón-Candia et al., 2023; Jarick & Kingstone, 2015), and the human eye's distinctive morphology facilitates its processing (Batki et al., 2000; Itier & Batty, 2009; Maurer et al., 2002; Shi et al., 2025). The uniquely exposed sclera, thought to have evolved to enhance gaze signaling (Kobayashi & Kohshima, 1997), supports processes such as

gaze following, automatic attentional capture, and attentional orienting (Driver et al., 1999; Emery, 2000; Gobbini & Haxby, 2007; Morrisey et al., 2019; Theeuwes & van der Stigchel, 2006; Ulloa et al., 2018). These effects likely depend on the high-contrast relation between iris and sclera, which enables efficient extraction of directional information.

Following this rationale, errors on incongruent trials can be attributed to spatial interference, while errors on congruent trials may result from the visual salience of the sclera, which is positioned closer to the central fixation point in these trials (i.e., the participant's focus area). Specifically, when the sclera appears on the side opposite the correct response direction, its high contrast may trigger response capture toward the incorrect side. If participants initially rely on this salient feature, it could account for the drop in accuracy on fast congruent trials, thereby producing the reversed CAF pattern observed with gaze stimuli. A fast response automatically triggered by the more visually prominent part of the face—the sclera—might be the source of the additional conflict hypothesized above, as it would activate the response opposite to the correct iris's direction response (**Figure 1**).

Furthermore, the RCE in RTs may partly arise from these perceptual characteristics. According to the dual-route framework, information conveyed by the automatic route is either inhibited (Ridderinkhof, 2002a), or dissipates quickly over time (Hommel, 1993) during response selection. Once the initial spatial code and that triggered by sclera salience are inhibited or decay, response selection may instead be guided by the iris, which conveys clearer directional information due to its contrast with the surrounding sclera (Kobayashi & Kohshima, 1997; Ulloa et al., 2018).

The emergence of the RCE would thus depend on the interaction between the asymmetrical contrast of the iris-sclera configuration and the task-irrelevant spatial code. Accordingly, congruent trials may involve an initial automatic response capture triggered by the salient sclera, which must first be inhibited or allowed to decay before the correct response to the iris side can be executed. This delay in response selection may lead to slower response latencies on congruent trials, thereby producing RCE.

The two experiment presented in this paper, pre-registered at Open Science Framework (OSF; **Transparency and Openness** section), aimed to test this hypothesis by designing two types of non-social targets that mimicked the asymmetrical contrast

properties of gaze stimuli and their inverse counterpart. This manipulation was intended to isolate the contribution of low-level perceptual contrast while avoiding the influence of socially driven processes.

Experiment 1

Experiment 1 tested whether the RCE could be elicited using non-social stimuli that mimic the sclera-iris contrast polarity of gaze. Specifically, participants performed a spatial Stroop task with two types of arrow targets (**Figure 2**): one designed to simulate the contrast between the sclera and iris (*gaze-similar* arrows), and another with the opposite contrast pattern (*gaze-opposite* arrows). Based on the assumption that contrast polarity might facilitate the reversed effect, we expected gaze-similar arrows to elicit an RCE.

It was also hypothesized that if the sclera modulates the automatic response capture mechanism, gaze-similar arrows would reproduce the CAF pattern previously observed with gaze stimuli: reduced accuracy for both congruent and incongruent trials, with lower accuracy for congruent trials in the fastest responses.

In contrast, gaze-opposite arrows were expected to produce a standard SCE, along with CAF patterns typically associated with non-social stimuli like standard arrows.

Method

Participants

Thirty-six adults (27 females; mean age = 21.8 years, *SD* = 3.4) participated in the study. All were students from the University of Granada who provided informed consent and received compensation in the form of either 6 euros or partial course credit, according to their preference. Participants were naïve to the purpose of the experiment. The study was conducted in accordance with the ethical guidelines of the University of Granada (3232/CEIH/2023) and the 1964 Declaration of Helsinki. Data collection took place during April and May 2024. Outlier detection was based on participants' mean accuracy scores, with any participant falling more than 3 *SD*s below the group mean across conditions being excluded from the analysis.

Power analyses were conducted to assess whether a sample of 36 participants, based on Marotta et al. (2018), was sufficient to detect the expected effects (the script and dataset are available in OSF, see **Transparency and Openness**). Focusing on the gaze congruency effect with an estimated effect size of $d_z = 0.49$, a paired-sample *t* test using the *pwr* package (Champely et al., 2022) indicated a power of .81. Additionally, an ANOVA-based simulation using the *Superpower* (Lakens & Caldwell, 2021) estimated a power of .99 for the interaction between target type and congruency, based on Marotta et al.'s dataset, with an effect size of Cohen's $f = 1.08$.

Apparatus and Stimuli

The task was programmed in OpenSesame (Mathôt et al., 2012) and run locally using JATOS (Lange et al., 2015), although the experiment was conducted in person. It was run on a standard Intel Core i5 PC with an 18.5-inch widescreen monitor (resolution: 1366 × 768 pixels, aspect ratio: 16:9, refresh rate: 59.79 Hz, color depth: 8-bit).

Two types of arrow stimuli were created (**Figure 2**). Gaze-similar arrows replicated the contrast polarity found in iris-sclera configurations, featuring a darker less salient arrowhead and lighter tail. In contrast, gaze-opposite arrows inverted this pattern, with a lighter head and darker less salient tail. Both stimulus types were designed using a linear gradient fill with four gradient stops transitioning from dark grey to white. The background against which the arrows were presented was a uniform grey.

Procedure

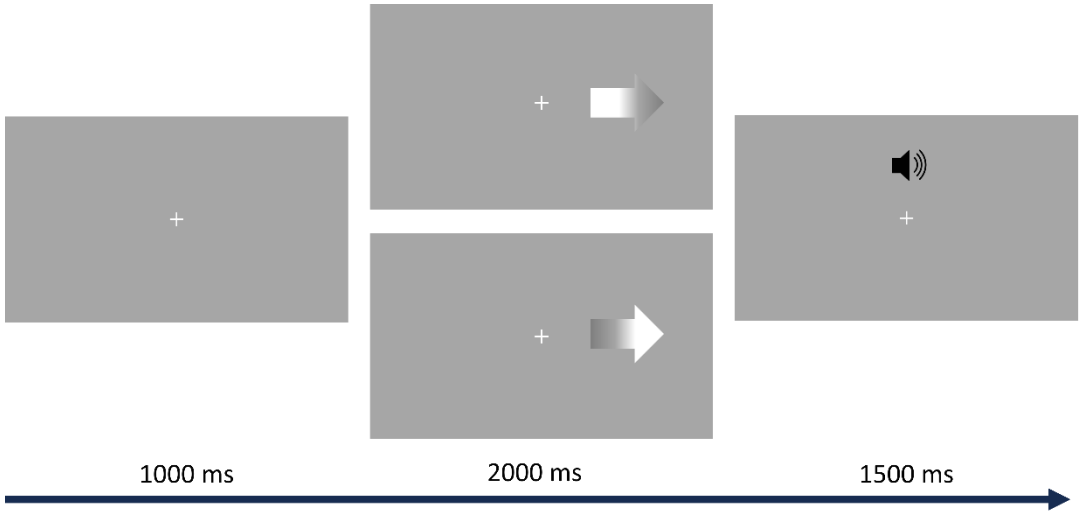
The procedure was adapted from Marotta et al. (2018). Participants were seated approximately 60 cm from the computer screen in a dimly lit room. After completing 15 practice trials, they proceeded to four experimental blocks with a short break between each. A total of 256 experimental trials were presented, 64 trials per condition (congruency, × target type). The four conditions were intermixed within each block.

Participants performed a spatial Stroop task in which they were instructed to respond as quickly and accurately as possible to the direction indicated by the arrow (left or right), while ignoring its spatial location. Each trial began with a central fixation cross presented for 1000 ms, followed by a lateralized arrow target (pointing left or right), which remained onscreen until the participant responded or for a maximum of 2000 ms

(**Figure 2**). Incorrect responses triggered auditory feedback lasting 1500 ms. Participants were instructed to maintain fixation on the central cross and to press the "C" key for left-pointing arrows and the "M" key for right-pointing arrows, regardless of the stimulus's spatial position.

Figure 2

Schematic Representation of Trial Sequence



Note. Schematic representation of trial sequence. The example depicts congruent trials for both target types: gaze-similar arrows (top) and gaze-opposite arrows (bottom). The speaker icon indicates the auditory feedback presented after incorrect responses.

Design and Statistical Analysis

The study employed a 2 × 2 within-participants design with the factors target type (gaze-similar vs. gaze-opposite) and congruency (congruent vs. incongruent trials). To examine temporal dynamics, CAF analyses were conducted by sorting RTs from fastest to slowest and dividing them into five equal-sized bins (20% each), following prior procedures (e.g., Hübner & Töbel, 2019; Ponce et al., 2025a). Accuracy was calculated for each participant across all combinations of target type, congruency, and bin, yielding a 2 × 2 × 5 structure. Repeated-measures ANOVAs were used to test for interaction effects: a 2 × 2 model for the RT and accuracy analyses, and a 2 × 2 × 5 model for the CAF analysis. Post-hoc contrasts were conducted where appropriate, with Bonferroni adjustment to control for multiple comparisons.

In addition to the preregistered analyses, one exploratory (non-preregistered) analysis was conducted. Delta function analyses were used to assess whether an RCE

might emerge at slower response latencies, as previously reported with non-social stimuli (Tanaka et al., 2025). To compute delta values, quantile averaging was employed (Ratcliff, 1979). Correct RTs were sorted and quantile values were extracted at the .1, .3, .5, .7, and .9 probabilities using R's quantile function with the type 8 estimator (Hyndman & Fan, 1996), following the same procedures as in previous studies (e.g., Grange, 2016; Ponce et al., 2025b). For each target type and quantile, delta values were computed by subtracting the mean RT on congruent trials from that on incongruent trials. This resulted in a 2 × 5 design (target type × quantile). Bonferroni-adjusted post-hoc contrasts were applied, along with one-sample *t* tests against zero to test whether Stroop effects at each quantile differed from zero.

Transparency and Openness

We reported how we determined our sample size, as well as all data exclusions, manipulations, and measures. All hypotheses, experimental design, and analysis plans were preregistered prior to data collection. The preregistrations, along with task materials, stimuli, datasets, and analysis scripts, are publicly available on OSF (https://osf.io/wzkqb/). Data were analyzed using R (Version 4.3.2; R Core Team, 2023) in RStudio (Version 2025; Posit Team, 2025). For statistical analyses we used *rstatix* (Version 0.7.2; Kassambara, 2023), for confidence intervals we used *papaja* (Version 0.1.2; Aust & Barth, 2023), and for data processing and visualization we used the *tidyverse* collection (Wickham et al., 2019).

Results

Following the preregistered plan of analysis, the data from one participant were excluded due to low accuracy (i.e., more than 3 *SD*s below the group mean). Practice trials were omitted from all analyses. Consistent with the criteria used by Marotta et al. (2018), trials with RTs below 200 ms (0.01%) or above 1300 ms (0.25%), as well as incorrect responses (2.75%), were excluded from the RT analyses. The same trimming procedure was applied to the distributional analyses (i.e., CAF and delta functions). Greenhouse-Geisser corrections were applied where violations of the sphericity assumption occurred. **Table 1** showed mean RTs for condition and experiment.

Table 1. Mean Reaction Times (RT, in milliseconds) and Percentages of Incorrect Responses (IR) by condition and experiment.

		Experiment 1		Experiment 2			
				Absent		Present	
		congruent	incongruent	congruent	incongruent	congruent	incongruent
Gaze-similar	RT	458 (57)	484 (68)	467 (89)	501 (91)	634 (71)	637 (84)
	IR	1.79 % (2.15)	3.75 % (4.61)	1.49 % (1.76)	5.80 % (4.80)	5.57 % (5.13)	8.43 % (11.88)
Gaze-opposite	RT	450 (59)	486 (70)	451 (80)	497 (89)	601 (81)	610 (88)
	IR	1.03 % (1.61)	4.17 % (4.94)	1.32 % (1.67)	5.44 % (4.19)	2.62 % (4.27)	3.74 % (3.94)

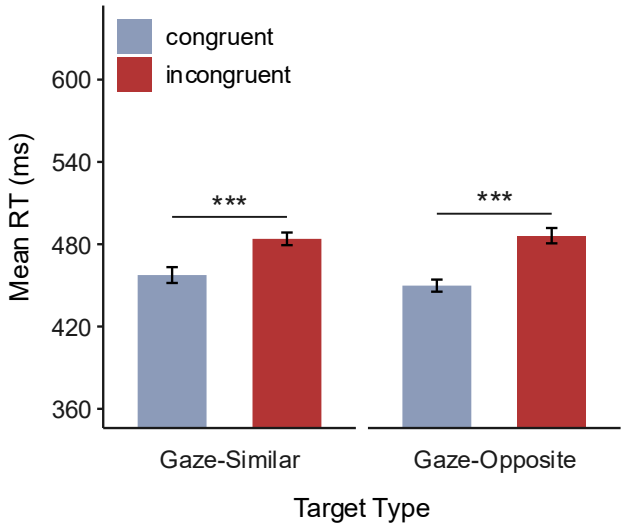
Note. Standard deviations of RTs and IRs are reported in parentheses. In Experiment 2, the labels "Absent" and "Present" refer to the absence or presence of background in which the stimuli were embedded.

Reaction Time

The ANOVA on RTs revealed a main effect of congruency, $F(1, 34) = 79.35$, $p < .001$, $\eta_p^2 = .70$, with faster responses on congruent trials (454 ms) than on incongruent trials (485 ms). A significant interaction between target type and congruency was also found, $F(1, 34) = 5.99$, $p = .020$, $\eta_p^2 = .15$. A direct comparison across target types indicated that gaze-opposite arrows elicited significantly faster responses on congruent trials than gaze-similar arrows, $t(34) = 2.97$, $p = .005$, $d_z = 0.50$, whereas no difference was observed on incongruent trials. Nevertheless, and importantly, both gaze-similar, $t(34) = -6.34$, $p < .001$, $d_z = -1.07$, and gaze-opposite arrows, $t(34) = -9.13$, $p < .001$, $d_z = -1.54$, elicited an SCE, with faster responses on congruent than incongruent trials (**Figure 3**).

Figure 3

Mean RTs by Congruency for each Target Type



Note. Mean RTs (in milliseconds) are shown by congruency for each target type (congruent trials in blue-purple, incongruent in red). Error bars indicate 95% confidence intervals computed with the Cousineau–Morey adjustment method (Morey, 2008). Asterisks indicate significance levels: $p < .05$ *, $p < .01$ **, $p < .001$ ***.

Accuracy

The accuracy analysis revealed a main effect of congruency, $F(1, 34) = 11.58$, $p = .002$, $\eta_p^2 = .25$. Participants made fewer errors on congruent trials (1.41%) than on incongruent trials (3.96%). No other effects reached statistical significance.

Distribution Analysis

The three-way interaction in the CAF analyses did not reach significance, $F(2.79, 94.97) = 0.84$, $p = .469$, $\eta_p^2 = .02$. However, there was a significant two-way interaction between congruency and bin, $F(2.08, 70.69) = 25.32$, $p < .001$, $\eta_p^2 = .43$. Follow-up comparisons revealed that accuracy was lower on incongruent compared to congruent trials in bin 1, $t(69) = 6.98$, $p < .001$, $d_z = 0.83$, and bin 2, $t(69) = 2.05$, $p = .044$, $d_z = 0.25$. In addition, bin 1 showed significantly lower accuracy than subsequent bins only for incongruent trials (**Figure 4A**).

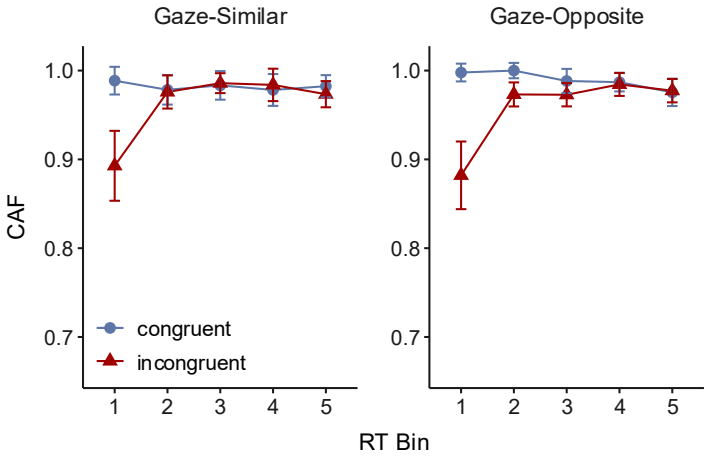
For the delta function analysis, the interaction between target type and quantile was not significant. However, a main effect of target type was observed, $F(1, 34) = 34.00$, p

= .011, η_p^2 = .18, indicating a larger spatial Stroop effect for gaze-opposite targets (37 ms) compared to gaze-similar targets (25 ms). A main effect of quantile was also found, $F(1.65, 58.13) = 5.55$, p = .010, η_p^2 = .14, showing that the Stroop effect was larger at earlier quantiles (first and second) than at middle quantiles (third and fourth), suggesting a slight decrease in interference with increasing response times, from 38ms at the highest point to 24 ms at the lowest. Nevertheless, one-sample *t* tests against zero confirmed that the SCE differed from zero across all quantiles (*ps* < .05; **Figure 4B**).

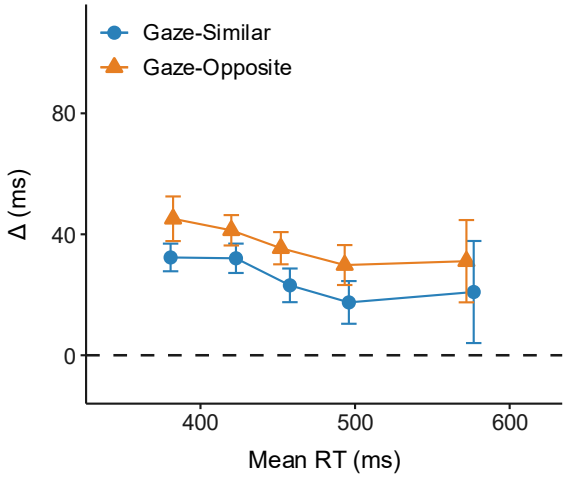
Figure 4

Distributional Analysis from Experiment 1

A)



B)



Note. Distributional results from the experiment 1: A) CAF showing accuracy across five RT bins as a function of congruency and target type (congruent trials in blue-purple circles, incongruent in red triangles). B) Delta plot depicting the spatial Stroop effect across quantiles by target type (gaze-similar in light blue circles, gaze-opposite in orange triangles), plotted against the average RT for each quantile point. The dashed line at zero indicates the absence of a congruency effect. Error bars indicate 95% confidence intervals computed with the Cousineau–Morey adjustment method (Morey, 2008).

Discussion

Experiment 1 examined whether simulating gaze-like contrast polarity (i.e., iris-sclera contrast asymmetry) would elicit an RCE or reproduce the distributional patterns

typically observed with gaze stimuli. The results did not support this hypothesis: both gaze-similar and gaze-opposite arrows produced SCEs, with faster and more accurate responses on congruent trials.

Distributional analyses supported these findings, no reversal was observed in either distributional analysis. CAF results showed reduced accuracy for fast incongruent responses, a pattern typically observed with non-social stimuli (Ponce et al., 2025a; Torres-Quesada et al., 2022), consistently across both arrow types. Delta plots revealed a consistent SCE across the distribution, with interference slightly decreasing at slower quantiles. This pattern aligns with temporal-decay (Hommel, 1993) or active suppression accounts (Ridderinkhof, 2002a, 2002b). However, unlike other location-based tasks such as the visual Simon task results (Luo & Proctor, 2019; Mittelstädt & Miller, 2020; Zhong et al., 2020), the interference persisted even at the slowest quantiles, suggesting that spatial interference may be stronger in the spatial Stroop task (see **General Discussion**). Interestingly, the smaller Stroop effect for gaze-similar arrows was driven by faster congruent responses in the gaze-opposite condition, suggesting a facilitation effect when the white arrowhead matched the spatial location. This is interesting as it shows that our manipulation was somehow successful in speeding up responses when the contrast polarity was congruent with the arrow direction. In other words, on congruent trials, when contrast polarity asymmetry was incongruent with the arrow direction (i.e., more salient in the opposite side of the target arrowhead, as with the iris-sclera, responses were 8 ms slower). Nevertheless, a SCE was still observed, opposite to the predicted RCE in case this was due to iris-sclera contrast asymmetry.

Thus, these findings suggest that contrast asymmetry alone is insufficient to reproduce the behavioral and temporal dynamics of gaze-related interference. However, such features may still play a role under conditions where spatial interference is reduced. As noted earlier, increasing background complexity has been shown to reduce the SCE in arrow stimuli (Román-Caballero et al., 2021a, 2021b; Tanaka et al., 2024), potentially by delaying access to directional information and allowing the spatial code to decay (Román-Caballero et al., 2021a, 2021b) and/or by enhancing or accelerating the activation of inhibitory mechanisms (Ponce et al., 2025b; Tanaka et al., 2025). Building on this, Experiment 2 tested whether embedding contrast-manipulated arrows within a complex

background would reduce spatial interference and enhance the influence of perceptual contrast, enough to elicit an RCE.

Experiment 2

To further investigate whether low-level perceptual contrast can drive RCEs under reduced spatial interference, Experiment 2 introduced a background manipulation to the same task and stimuli used in Experiment 1. While contrast asymmetry alone did not elicit an RCE, previous studies suggest that visual complexity may reduce spatial interference by delaying access to directional information and/or enhancing early inhibition processes (Román-Caballero et al., 2021a, 2021b; Tanaka et al., 2024, 2025; Ponce et al., 2025b). Under such conditions, perceptual features like contrast polarity may exert a stronger influence on response selection.

To test this, arrow targets were presented either without background, as in Experiment 1 (background-absent condition), or embedded within a visually complex rectangular background (background-present; **Figure 5**). This within-participants manipulation allowed us to assess whether background presence modulates congruency effects and facilitates the emergence of an RCE with contrast-manipulated arrows.

In the background-absent condition, we expected to replicate the results of Experiment 1, in both mean-level and distributional analyses (i.e., SCE in RT and accuracy, typical CAF and delta patterns). In the background-present condition, we hypothesized that gaze-similar arrows would elicit an RCE, while gaze-opposite arrows would produce a reduced or absent SCE. At the distributional level, for gaze-similar stimuli, we anticipated a drop in accuracy for fast congruent and incongruent trials in CAFs, the former reflecting early interference from the salient, task-irrelevant scleral-like feature, and a reversed pattern in delta functions emerging at the medium and slowest quantiles. In contrast, gaze-opposite stimuli were expected to show a diminished conflict effect, potentially leading to flat delta functions across the distribution.

Method

Participants

A total of 40 adults participated in this experiment (30 female; mean age = 22.5 years, *SD* = 3.0). All participants were undergraduate students at the University of Granada and received partial course credit for their participation. Data collection took place in June 2024. The study adhered to the same ethical guidelines as Experiment 1, and the outlier detection procedure was also identical.

Power analyses were conducted using the same approach as in Experiment 1, given that the primary design elements and critical comparisons (e.g., target type and congruency) remained unchanged. Although an additional factor was introduced (background condition: absent vs. present), it was not expected to substantially affect the required sample size. Nonetheless, the sample was increased to 40 participants to account for potential measurement noise in the online data collection.

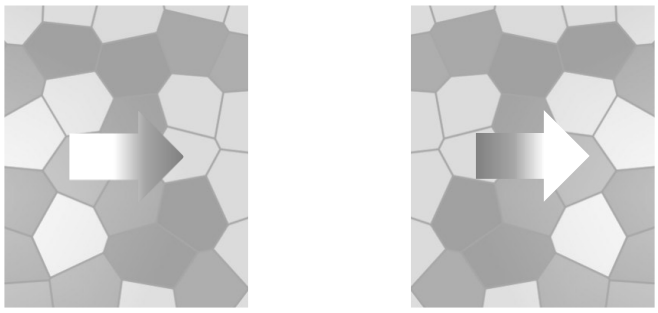
Apparatus and Stimuli

The study was conducted online. The task was programmed using OpenSesame (Mathôt et al., 2021) and administered via JATOS (Lange et al., 2015). The task structure and arrow stimuli were identical to those in Experiment 1, with the addition of the background manipulation. The background-absent condition replicated the procedure from Experiment 1, while in the background-present condition, targets were embedded within a visually complex background. Two types of backgrounds were used, adapted from the stimuli of Román-Caballero et al. (2021a) and modified to avoid face-like configurations and employ a greyscale palette. One background was a mirrored version of the other (**Figure 5**).

Figure 5

Arrow stimuli used in Experiment 2 under the Background-Present Condition

A) B)



Note. Examples of the arrow stimuli used in Experiment 2 under the background-present condition. A) Gaze-similar arrows (darker arrowhead, lighter tail) shown with one version of the background. B) Gaze-opposite arrows (lighter arrowhead, darker tail) shown with the mirrored version of the background.

Procedure

The procedure was identical to that of Experiment 1 (see **Figure 2**), with the exception of the added background condition. The task consisted of two main blocks: one comprising background-absent trials, and one with background-present trials. Block order was counterbalanced across participants. Each block was preceded by 10 practice trials and consisted of two sub-blocks of 128 trials each, with a brief pause in between, resulting in 256 experimental trials per block (i.e., 64 trials per experimental condition, as in Experiment 1).

Design and Statistical Analysis

The experiment employed a within-participants 2 × 2 × 2 design, which the factors background (absent vs. present), target type (gaze-similar vs. gaze-opposite), and congruency (congruent vs. incongruent). RT trimming criteria were applied as in Experiment 1. Distributional analyses, including CAFs and delta functions, followed the same procedures used in the previous experiment, with the background factor incorporated into the analytical framework. Post-hoc contrasts were conducted where appropriate, with Bonferroni adjustment to control for multiple comparisons.

Transparency and Openness

We followed the same guidelines regarding transparency and openness as in Experiment 1. The preregistration, task materials, stimuli, datasets, and analysis scripts are also available on OSF (https://osf.io/wzkqb/). Data were analyzed using the same software and R packages as in the previous experiment.

Results

Data from one participant was excluded due to consistently low accuracy (i.e., more than 3 *SD*s below the sample mean). Practice trials were not included in any analyses. Following the same trimming criteria used in Experiment 1, trials with RTs faster than 200 ms (0.03%) and slower than 1300 ms (1.55%) were removed, along with incorrect responses (4.79%), for all RT-based analyses. The trimming procedures were also applied to the distributional analyses (CAF and delta functions). When the assumption of sphericity was violated, Greenhouse-Geisser corrections were applied.

Reaction Time

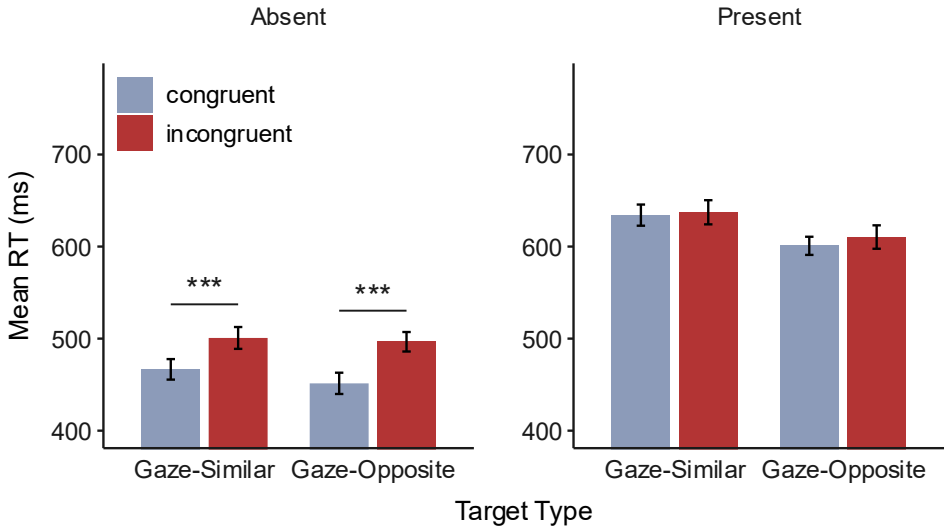
The RT analysis revealed a significant main effect of background, $F(1, 38) = 267.90$, $p < .001$, $\eta_p^2 = .88$, with faster responses observed in the background-absent condition (479 ms) compared to the background-present condition (621 ms). A main effect of target type also emerged, $F(1, 38) = 59.12$, $p < .001$, $\eta_p^2 = .61$, reflecting slower responses for gaze-similar arrows (560 ms) than for gaze-opposite arrows (540 ms). As in Experiment 1, a main effect of congruency was found, $F(1, 38) = 43.26$, $p < .001$, $\eta_p^2 = .53$, with faster responses on congruent (539 ms) than incongruent trials (561 ms).

The three-way interaction between background, target type and congruency was not significant. However, all two-way interactions reached significance. Of particular interest, the background × congruency interaction was significant, $F(1, 38) = 48.35$, $p < .001$, $\eta_p^2 = .56$. Post-hoc comparisons showed that when the background was absent, congruent trials were significantly faster than incongruent ones, $t(77) = -10.67$, $p < .001$, $d_z = -1.21$, replicating the congruency effect observed in Experiment 1. In contrast, when the background was present, no significant difference was found between congruent and

incongruent trials (p = .098), suggesting the absence of the spatial interference effect (**Figure 6**).[4]

Figure 6

Mean RTs across Congruency by Target Type and Background condition



Note. Mean RTs across congruency conditions for each combination of target type and background condition (absent vs. present), congruent trials in blue-purple, incongruent in red. Error bars represent standard errors of the mean, adjusted using Cousineau-Morey method (Morey, 2008). Error bars indicate 95% confidence intervals computed with the Cousineau–Morey adjustment method (Morey, 2008). Asterisks denote significance levels: p < .05 *, p < .01 **, p < .001 ***.

Additionally, the interaction between background and target types was significant, $F(1, 38) = 21.12$, $p < .001$, $\eta^2_p = .36$. Although gaze-similar arrows elicited slower RTs in both background conditions, the difference was larger in the background-present condition (30 ms), $t(77) = 8.37$, $p < .001$, $d_z = 0.95$, than in the background-absent condition (10 ms), $t(77) = 3.24$, $p = .002$, $d_z = 0.36$. Finally, the target type × congruency interaction was also significant, $F(1, 38) = 5.73$, $p = .022$, $\eta^2p = .13$, as in Experiment 1. Both target types elicited an SCE, but it was larger for gaze-opposite arrows, mainly due to faster

[4] For completeness, we also tested the congruency effect within each target type, represented in **Figure 6**. When the background was absent, both gaze-similar, $t(38) = -6.01$, $p < .001$, $d_z = -0.96$, and gaze-opposite targets, $t(38) = -9.62$, $p < .001$, $d_z = -1.54$, showed significant SCEs. In the background-present condition, neither target type showed a significant effect, gaze-similar, $t(38) = -0.54$, $p = .60$, $d_z = -0.09$, and gaze-opposite, $t(38) = -1.96$, $p = .058$, $d_z = -0.31$.

responses on congruent trials, $t(77) = 7.33$, $p < .001$, $d_z = 0.83$; the difference in incongruent trials was smaller yet still significant, $t(77) = 4.29$, $p < .001$, $d_z = 0.49$.

Importantly, an additional analysis including block order (i.e., whether participants began with the background-absent or background-present block) as a between-participants factor revealed no significant main or interaction effects involving block sequence (all *ps* > .06), indicating that the observed results were not influenced by block presentation order.

Accuracy

A main effect of background was observed, $F(1, 38) = 5.28$, $p = .027$, $\eta_p^2 = .12$, with participants making fewer errors in the background-absent condition (3.51 %) compared to the background-present condition (5.09 %). A significant main effect of target type also emerged, $F(1, 38) = 13.05$, $p < .001$, $\eta_p^2 = .26$, with gaze-similar producing higher error rates (5.33 %) than gaze-opposite stimuli (3.28 %). Additionally, there was a main effect of congruency, $F(1, 38) = 19.49$, $p < .001$, $\eta_p^2 = .34$, indicating that congruent trials elicited fewer errors (2.75 %) than incongruent trials (5.85 %).

Similar to RT analysis, the three-way interaction (background × target type × congruency) was not significant. However, a significant interaction between background and congruency was observed, $F(1, 38) = 4.43$, $p = .042$, $\eta_p^2 = .10$. Although both background conditions elicited more errors on incongruent than congruent trials, the difference between congruent and incongruent trials was smaller in the background-present condition, *diff.* = 1.99%, $t(77) = 2.11$, $p = .038$, $d_z = 0.24$, compared to background-absent condition, *diff.* = 4.21%, $t(77) = 8.16$, $p < .001$, $d_z = 0.92$. Additionally, a significant interaction between background and target type emerged, $F(1, 38) = 9.56$, $p = .004$, $\eta_p^2 = .20$, with gaze-similar producing more errors than gaze-opposite targets in the background-present condition (7.00 % vs. 3.18 %), but not in the background-absent condition.

Distribution Analysis

CAF analyses (**Figure 7A**) did not reveal a significant four-way interaction (background × target type × congruency × bin). However, a significant three-way interaction between background, congruency and bin was found, $F(1.72, 65.46) = 5.47$, $p =$

.009, η_p^2 = .13. Follow-up comparisons indicated an SCE in the first, $t(77) = 8.98$, $p < .001$, d_z = 1.02, and second bins, $t(77) = 2.91$, $p = .005$, $d_z = 0.33$, when the background was absent. A smaller but still significant SCE was also observed in the first bin when the background was present, $t(77) = 2.17$, $p = .033$, $d_z = 0.25$. Additionally, in the background-absent condition, incongruent trials showed reduced accuracy in the first bin compared to later bins. In the background-present condition, both congruent and incongruent trials exhibited reduced accuracy in the first bin relative to the subsequent bins. Nevertheless, a similar pattern was observed for both gaze-similar and gaze-opposite targets (see **Figure 7A**).

Moreover, a significant interaction between background, target type, and bin was observed, $F(2.34, 88.89) = 7.79$, $p < .001$, η_p^2 = .17. Post-hoc comparisons revealed that differences between target types were present only in the background-present condition, where gaze-similar targets elicited higher error rates across most bins (except the third), than gaze-opposite. In contrast, no significant differences between target types were observed in any bin in the background-absent condition, replicating the pattern observed in Experiment 1.

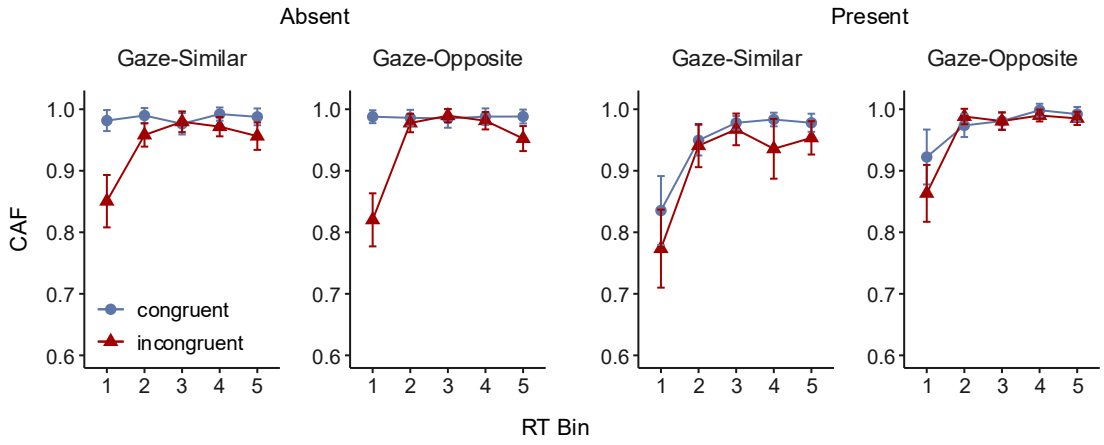
Delta plot analysis (**Figure 7B**) revealed a main effect of background, $F(1, 38) = 40.60$, $p < .001$, η_p^2 = .52, with larger congruency effects observed in the background-absent condition (39 ms) compared to the background-present condition (7 ms), as expected. A main effect of target type also emerged, $F(1, 38) = 8.12$, $p < .007$, η_p^2 = .18, showing that gaze-opposite targets (29 ms) elicited a larger effect than gaze-similar targets (17 ms). Neither the tree-way interaction nor the two-way interactions were significant.

Planned one-sample *t* tests against zero in the background-absent condition confirmed the presence of an SCE across the entire distribution (ps < .05), with a marginal effect for gaze-similar targets in the fifth quantile ($p = .06$). In the background-present condition, an SCE was only evident in the first quantile for both target types, and in the third quantile for gaze-opposite targets. However, in no case was a significant reversed effect observed.

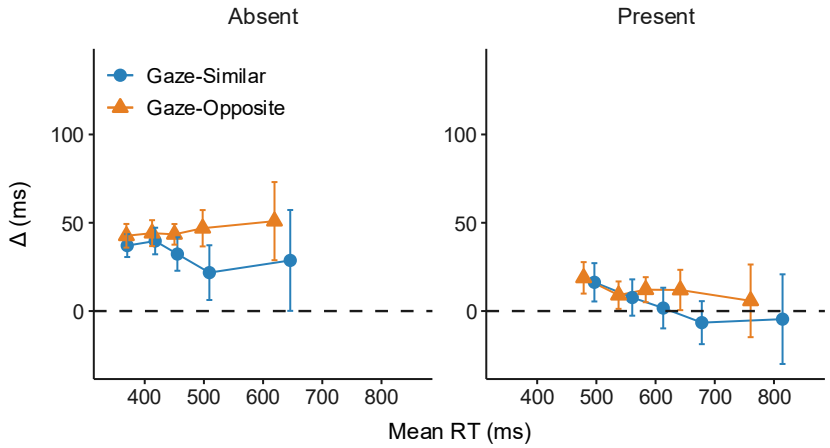
Figure 7

Distributional Analysis from Experiment 2

A)



B)



Note. Distributional results from the Experiment 2. A) CAF showing accuracy across five RT bins for congruent and incongruent trials, separated by target type and background condition (congruent trials in blue-purple circles, incongruent in red triangles). B) Delta plot depicting the spatial Stroop effect as a function of mean RT quantiles, plotted by target type and background condition (gaze-similar in light blue circles, gaze-opposite in orange triangles). Error bars reflect standard errors of the mean, adjusted using Cousineau-Morey method (Morey, 2008).

Discussion

Experiment 2 aimed to test whether embedding the contrast-manipulated arrows from Experiment 1 within a visually complex background (**Figure 5**), could reduce spatial interference and facilitate the emergence of an RCE for gaze-similar arrows. The results

did not support this hypothesis: the RCE did not emerge neither at the mean level nor in the distributional analyses.

On the one hand, the results of Experiment 1 were successfully replicated in the background-absent condition. A robust SCE was observed regardless of target type, both in RT and accuracy. Distributional analyses also confirmed a typical non-social pattern: reduced accuracy for incongruent trials in the fastest responses (CAF) and a consistent SCE across the entire RT distribution (delta plot).

On the other hand, and consistent with prior findings (Román-Caballero et al., 2021a, 2021b; Tanaka et al., 2024, 2025), the presence of a complex background effectively reduced the magnitude of the SCE. At the mean level, the congruency effect was no longer evident, and at the distributional level it was restricted to specific quantiles.

Interestingly, the CAF patterns revealed a significant drop in accuracy not only for incongruent trials, but also for congruent trials in the first bin compared to later bins, a pattern previously associated with social stimuli (Ponce et al., 2025a), although no reversion was observed across any point of the CAF distribution. Such modulation may reflect increased difficulty in extracting directional information in combination with automatic response capture. However, the fact that no reversion was ever observed indicates that iris-sclera asymmetrical contrast is not responsible for the RCE observed with gaze.

General Discussion

Across two preregistered experiments, we tested whether low-level contrast polarity—designed to mimic the asymmetric iris-sclera configuration of human eyes (Itier & Batty, 2009; Shi et al., 2025; Kobayashi & Kohshima, 1997; Yang et al., 2015)—can account for the RCE typically observed with gaze targets in spatial Stroop tasks. The results are straightforward: contrast asymmetry alone did not elicit an RCE. Both in the absence of background (Experiment 1) and when stimuli were embedded in visually complex background (Experiment 2), arrows with "gaze-similar" contrast produced SCEs or, at most, a marked reduction of interference, but never a reversal at the mean or distributional levels.

In Experiment 1, where arrows were presented without a background, both target types elicited robust SCEs in RTs and accuracy. Distributional analyses supported this typical non-social pattern, showing reduced accuracy for fast incongruent responses and an SCE across the RT distribution. Crucially, gaze-similar arrows neither produced an RCE nor reproduced the reversed CAF pattern previously associated with gaze stimuli. These results indicate that contrast polarity alone is not sufficient to account for the RCE observed with gaze.

Experiment 2 introduced a complex background to test whether increased visual complexity would reduce spatial interference (Román-Caballero et al., 2021a, 2021b; Tanaka et al., 2024), and allow contrast polarity to exert a stronger influence. As expected, the background manipulation attenuated the SCE. However, no reversal emerged at either the mean level or in distributional analyses.

Despite the absence of an RCE, our manipulations uncovered additional patterns that shed light on how perceptual features and background complexity affect performance and its temporal dynamics. In turn, these findings contribute to a better understanding of the extent to which gaze-related effects might be shaped by perceptual and task-related factors.

The background manipulation was originally introduced to equate the perceptual complexity between gaze and arrow stimuli (Román-Caballero et al., 2021a). As in previous studies, embedding targets in complex backgrounds elicited slower and less accurate responses compared to no backgrounds conditions (Román-Caballero et al., 2021a; Tanaka et al., 2024, 2025). This pattern parallels findings that gaze stimuli generally produced slower RTs (Dalmaso et al., 2023; Ishikawa et al., 2021; Marotta et al., 2018, 2019) and higher error rates (Aranda-Martín et al., 2023; Hemmerich et al., 2022; Ishikawa et al., 2024; Marotta et al., 2019; Narganes-Pineda et al., 2022) compared to arrows.

From a social account perspective, the slowing of RTs has often been attributed to the social significance and complexity of gaze stimuli, which may induce greater exploration of their features (Marotta et al., 2018; Román-Caballero et al., 2021a). However, the same pattern can also reflect a more general perceptual mechanism: when task-relevant information is harder to extract due to surrounding visual complexity, responses slow and accuracy decreases. Consistent with this, studies on location-based

tasks show that targets with reduced discriminability leads to slower and less accurate responses (Ellinghaus, 2024; Hommel, 1993). Recent research suggests that perceptual demands contribute to gaze-related effects (Tanaka et al., 2024), potentially pointing to a mechanism that gaze may share with other complex stimuli.

At the distributional level, the background manipulation also revealed notable conflict dynamics. In the background-present condition, the CAF showed reduced accuracy for the fastest responses in both congruent and incongruent trials, a pattern previously linked to gaze stimuli (Ponce et al., 2025a).

Typically, the drop in accuracy for incongruent trials within the fastest responses has been explained by an automatic response capture (Salzer et al., 2019; Torres-Quesada et al., 2022; van Campen et al., 2014, 2018): responses are more likely to be selected based on spatial location information before inhibition takes place (Ridderinkhof, 2002a, 2002b), and/or before the spatial code has decayed (Hommel, 1993).

However, this account does not explain why, in the background-present condition, congruent trials also showed reduced accuracy.

Even if responses were selected on the basis of target location, congruent trials should have yielded higher accuracy, as location and direction match. Instead, the results suggest that under increased perceptual difficulty, automatic capture may be shaped by additional stimulus- or task-related factors producing early costs across both trial types.

In this sense, the pattern partially resembles that observed with gaze stimuli (Ponce et al., 2025a), although without the additional process that gaze stimuli may recruit to produce a reversed CAF.

Delta function analyses provided complementary insights, capturing how interference evolves across the RT distribution (De Jong et al., 1994; Pratte et al., 2010; Speckman et al., 2008). Decreases in delta values are typically interpreted as reflecting either stronger inhibitory control or the decay of spatial codes (Mittelstädt & Miller, 2020; Mittelstädt et al., 2023a; Ridderinkhof, 2002a, 2002b).

In the background-present conditions, the conflict effect was already reduced at the very first quantiles compared to the background-absent condition (about 22 ms less at Q1, and 34 ms less at Q2).

This early reduction cannot be explained by passive decay alone, which would predict at least similar early interference (Hommel, 1993; Ulrich et al., 2015), or stronger interference given the high saliency of complex stimuli (Dolk et al., 2013; Ellinghaus et al., 2024; Rubichi et al., 1997; Stoffer, 1991). Instead, our results support a rapid engagement of inhibitory control mechanisms. Consistent with prior work, reduced target discriminability seems to modulate conflict dynamics beyond the fading of distractor activation (Ellinghaus et al., 2024).

This interpretation aligns with active inhibitory accounts that describe inhibition as a flexible, adaptive, top-down process (Burle et al., 2016; Meynier et al., 2009; Mittelstädt et al., 2023a; Scorolli et al., 2015), that vary in strength, onset time, and build-up rate (Ridderinkhof, 2002a, 2002b).

Recent studies propose similar dynamics for gaze (Ponce et al., 2025b; Tanaka et al., 2025): both gaze and arrows in complex contexts appear to trigger earlier inhibitory control. Where gaze differs, however, is in the subsequent dynamics: although reversals with arrows in complex backgrounds have been occasionally reported (Román-Caballero et al., 2021a, experiment 1; Tanaka et al., 2025, supplemental material), gaze stimuli have consistently shown a robust reversal across the remainder of the distribution (Ponce et al., 2025b).

Our results also highlight task-related characteristics of the spatial Stroop. In both Experiment 1 and the background-absent condition of Experiment 2, spatial Stroop interference persisted throughout the RT distribution, except for a small reduction at the last quantile for gaze-similar targets in Experiment 2. This contrasts with other location-based tasks, such as the visual Simon task, where conflict typically diminishes over time or disappears at slower responses (Luo & Proctor, 2019; Mittelstädt & Miller, 2020; Zhong et al., 2020).

Persistence has been observed before in the spatial Stroop task (e.g., Castel et al., 2007, figure 2; Juncos-Rabadán et al., 2008, see *t* tests performed with the youngest group; Ponce et al., 2025b; Tanaka et al., 2025, see experiment 1) and likely reflects the dual overlap characteristic of this task: spatial location (i.e., task-irrelevant information) interferes both with the response mappings (S–R overlap) but also with the relevant dimension (S–S overlap), namely the stimulus's direction (Kornblum, 1992; Viviani et al.,

2024). Such layered interference may explain the robustness of SCEs and their persistence across the RT distribution in the background-absent condition, potentially reflecting interference arising at multiple loci and stages (Banich, 2019; De Houwer, 2003; Parris et al., 2022). Indeed, evidence seems to suggest that S–S and S–R overlaps differ in how they elicit and resolve conflict (Li et al., 2014; Lou & Proctor, 2017; Scerrati et al., 2017; Torres-Quesada et al., 2022).

This distinction may also be important for understanding differences between gaze and arrow effects. Spatial location can trigger automatic response activation that competes with directional information not only during response selection but also at motor execution (Burle et al., 2016; Miller & Roüast, 2016; Treccani et al., 2018), potentially modulating arrows effects. Yet the RCE elicited by gaze has also been observed with verbal responses (Narganes-Pineda et al., 2022), suggesting that motor components are not strictly necessary. Future research should therefore examine whether motor factors provide an additional modulation of the RCE and how this interferes with the S-S vs. S-R distinction, which appears particularly relevant to gaze versus arrow research.

Beyond background effects, the contrast iris-sclera manipulation appears to interact with spatial interference asymmetrically across congruency. In both experiments, gaze-similar targets gaze-similar targets were harder to process (slower and less accurate), but they yielded a smaller SCE than gaze-opposite targets. This difference was largely due to faster congruent responses for gaze-opposite arrows, broadening the congruency gap. These patterns suggest that perceptual contrast interacts with congruency asymmetrically, possibly adding an extra layer of conflict. Similar effects have been reported when target discriminability is low or perceptual load is high, which may shift attentional resources toward target processing and reduce distractor interference (Ellinghaus et al., 2024; Lavie, 1995). Future studies should directly test how contrast-specific features modulate congruency.

Taken together, our findings contribute to the debate about whether gaze-induced RCEs reflect a social specific component or can be explained by domain-general mechanisms. Perceptual manipulations such as background complexity modulated conflict dynamics in ways partly resembling gaze stimuli, implying that non-social

factors play an important role. Yet, the absence of an RCE in our experiments underscores that these manipulations are not sufficient. Additional mechanisms, potentially linked to the unique perceptual configuration of eyes and/or their social meaning, are required to reproduce gaze's distinctive effects. This supports integrative accounts where the RCE emerge from the interaction of domain-general and domain-specific processes (Hemmerich et al., 2022; Marotta et al., 2018, 2019; Ponce et al., 2025a).

Nevertheless, two considerations should be kept in mind for future studies. First, although our contrast manipulations approximate iris–sclera asymmetry, they may not capture the full complexity of gaze processing. Our aim, however, was to model this asymmetry while minimizing any social-related component. Second, while our background manipulation successfully increased task difficulty, other forms of perceptual complexity (e.g., mosaic patterns, varied color palettes, etc.) may interact differently with target contrast features.

Overall, the present study highlights the value of distributional analyses for disentangling perceptual, task-related, and social contributions. By capturing early response dynamics that mean-level analyses may miss, these tools offer a more precise framework for understanding the conditions under which gaze effects and their absence emerge. This aligns with previous work recommending distributional approaches for examining subtle cognitive control dynamics (Balota & Yap, 2011; De Jong et al., 1994; Mittelstädt & Miller, 2020; Speckman et al., 2008).

Conclusion

The present study tested whether non-social stimuli mimicking the iris–sclera contrast of human eyes could reproduce the RCE typically observed with gaze. Across two preregistered experiments, contrast polarity alone proved insufficient: both in simple displays and under increased perceptual complexity, arrows with gaze-like contrast produced standard congruency effects or reduced interference, but never a reversal. Distributional analyses confirmed the typical non-social conflict patterns, with no evidence of the reversed dynamics consistently observed with gaze.

These findings suggest that while perceptual complexity modulates conflict dynamics, the RCE with gaze cannot be explained by contrast asymmetry alone and

likely emerges from the interaction of task dynamics and target characteristics with gaze-specific processes. Thus, gaze appears to engage both domain-general interference mechanisms and additional mechanisms unique to its perceptual and social significance, underscoring its special role in spatial conflict resolution.

3.4. Study 4. When Arrows Behave Like Eyes: Reversal of Spatial Stroop Interference by Visual Masking

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Study 4 is currently under review. The preprint is available at:

Ponce, R., Marotta, A., Román-Caballero, R., Tanaka, Y., Akçeşme, Ş., Chacón-Candia, J. A., Milliken, B., Casagrande, M., & Lupiáñez, J. (2025, October 11). When Arrows Behave Like Eyes: Reversal of Spatial Stroop Interference by Visual Masking. https://doi.org/10.31234/osf.io/ygdft_v2

Abstract

The Reversed Congruency Effect (RCE) typically observed with gaze targets has been rarely demonstrated with non-social stimuli like arrows targets. In a novel approach, we conducted two pre-registered experiments to investigate whether the RCE can be elicited using non-social stimuli (arrows) when directional information is visually masked. Participants performed a spatial Stroop task with arrows varying in perceptual complexity due to overlapping visual masks. Direction and spatial location were either congruent or incongruent. Remarkably, highly masked arrows elicited an RCE, with faster responses on incongruent trials. Distributional analyses showed reduced interference among the fastest responses and larger RCE in middle quantiles. Additionally, increased errors for both congruent and incongruent conditions were observed in the fastest responses, with congruent trials showing higher error rates, as previously observed with gaze targets. These findings suggest that the RCE reflects a dynamic interplay between early response capture and inhibitory control, shaped by the visual features of masked stimuli. Critically, they raise the possibility that similar perceptual constraints contribute to the RCE observed with gaze targets, offering a potential non-social mechanism underlying this effect. Our results highlight how visual complexity can modulate automatic activation and control processes, underscoring the value of distributional methods for revealing the temporal dynamics of interference.

Key Words: spatial Stroop task; Gaze versus Arrows; Reversed Congruency Effect; Distributional Analysis; Social Attention

Introduction

Research on social attention often investigates whether gaze-driven orienting relies on general mechanisms for processing directional cues or on specialized processes for interpreting others' intentions (Apperly & Butterfill, 2009; Cole & Millett, 2019). However, standard cueing paradigms yield similar effects for arrows and gaze (Chacón-Candia et al., 2023), underscoring the need for more information methods. One possibility is the recently widely used spatial interference paradigm (Lu & Proctor, 1995), typically implemented using the spatial Stroop task (e.g., Cañadas & Lupiáñez, 2012; Marotta et al., 2018).

In this task, participants are asked to respond to the direction (left or right) indicated by a lateralized target, such as an arrow or a gaze, while ignoring its spatial location (i.e., whether it appears to the left or right of fixation). Trials are considered congruent when the direction indicated by the stimulus matches its spatial location (e.g., a right-pointing arrow on the right side of fixation) and incongruent when it does not (e.g., a right-pointing arrow on the left side of fixation). Non-social stimuli, such as arrows, typically produce a standard congruency effect (SCE), characterized by faster responses on congruent than incongruent trials. In contrast, gaze stimuli often elicit a reversed congruency effect (RCE), with faster responses on incongruent trials (e.g., Hemmerich et al., 2022; Ishikawa et al., 2021).

The SCE is typically attributed to the asymmetric relationship between different stimulus dimensions, specifically, the task-relevant direction and the task-irrelevant spatial location relative to lateralized motor responses (Lu & Proctor, 1995; Viviani et al., 2024). According to Kornblum's (1992) taxonomy, this setup constitutes a Type 8 ensemble, characterized by Stimulus-Stimulus (S-S) and Stimulus-Response (S-R) dimensional overlap. Even when participants are explicitly instructed to focus on the relevant dimension (i.e., direction), spatial location still influences response selection and motor execution. This overlapping-dimensional interference suggests that conflict must be resolved at multiple levels such as task, stimulus, and response (Viviani et al., 2024).

The specific dynamics underlying the SCE have been further explained within the dual-route processing framework (e.g., Ponce et al., 2025a, 2025b; Tanaka et al., 2024, 2025a). Although this framework has been predominantly applied to explain the dynamics of Simon and Simon-like tasks (S-R overlap, e.g., Luo & Proctor, 2017; Scerrati et al., 2017; Torres-Quesada et al., 2022), its assumptions extend to the spatial Stroop task.

According to the dual-route framework information is processed along two parallel routes (Cohen et al., 1990; De Jong et al., 1994; Luo & Proctor, 2017, 2019; Mittelstädt & Miller, 2020; Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015): an automatic route that processes spatial information irrelevant to the task and a controlled route that processes task-relevant information (i.e., stimulus direction), based on the instructed S-R mapping (e.g., "Press the left-hand key if the stimulus is pointing or looking to the left"). On incongruent trials, these two routes activate competing responses. The automatic

route may trigger a response based on where the stimulus appears (see automatic response capture, Torres-Quesada et al., 2022; van Campen et al., 2014; 2018), while the controlled route tries to guide the response based on its direction (Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015). This conflict typically results in slower reaction times (RTs) and increased error rates.

However, the mechanisms underlying the RCE observed with gaze targets remain under debate. Several theoretical accounts have been proposed over time, emphasizing either a social component (Cañadas & Lupiañez, 2012; Edwards et al., 2020; Marotta et al., 2018), stimulus perceivability (Chen et al., 2022), or difficulties in accessing task-relevant information (Tanaka et al., 2024, 2025a). Other accounts have aimed to integrate both perspectives within a unified framework, proposing that gaze might trigger general mechanisms shared with arrows, and additional social-specific mechanisms (Hemmerich et al., 2022; Ponce et al., 2025a, 2025b; Román-Caballero et al., 2021a, 2021b). In other words, these accounts have proposed that social targets also trigger the cognitive mechanisms that lead to an SCE, but the final effect that is observed is reversed by the additional implication of social mechanisms.

Empirical research has explored the conditions under which the RCE emerges, providing important insights into the factors that shape this effect. It has been consistently observed with eye-gaze stimuli, whether presented as isolated eyes (Chacón-Candia et al., 2024; Ishikawa et al., 2021) or full-face targets (Cañadas & Lupiáñez, 2012; Hemmerich et al., 2022; Román-Caballero et al., 2021a). However, it does not appear with other directional stimuli like pointing hands or words (Bonventre & Marotta, 2023; Dalmaso et al., 2022; Hemmerich et al., 2022).

Interestingly, the RCE has also been observed with non-traditional cues, such as tongues (Tanaka et al., 2024), some animal faces (Ishikawa et al., 2024), inverted faces (Tanaka et al., 2023), and to a lesser extent with non-social targets (Román-Caballero et al., 2021a). These findings suggest that social meaning or stimulus familiarity may contribute to the effect but are not the only determining factors.

Developmental evidence supports the view that whereas the SCE is already shown by 4-year-old children the RCE emerges gradually with age. Aranda-Martín et al. (2022) found that, contrary to the effect observed in adult samples, gaze stimuli elicited

an SCE in children under 12 years, whereas adolescents (12–17 years) already exhibited the usual reversed effect measured commonly in adults.

Hemmerich et al. (2022) observed the usual SCE for non-social stimuli, either arrows or words, and the opposite RCE for social stimuli, i.e., gaze (either cropped eyes or full faces). However, by analyzing the congruency sequence effect, they showed that both social and non-social stimuli induced the same effect in the following trial. Thus, after both incongruent arrow trials and incongruent gaze trials, the same reduced standard congruency influence was observed, which manifested as an increase in the RCE for social stimuli, and a reduction in the SCE for non-social stimuli. Similarly, after both congruent arrow trials and congruent gaze trials, there was an increase in the standard congruency influence, manifested as a reduction in the RCE for social stimuli, and an increase in the SCE for non-social stimuli. Notably, this differential pattern emerged even when social and non-social stimuli were intermixed within the same experimental block.

Román-Caballero et al. (2021a, 2021b) showed that increasing the perceptual background complexity produced a similar effect, reducing the SCE for arrows and enhancing the RCE for gaze targets. In their study, arrows were presented against complex backgrounds to simulate the perceptual complexity of social stimuli, specifically eyes embedded in faces. They argued that the need to segregate the target from its background introduces a temporal delay in extracting task-relevant information. This delay allows the irrelevant spatial code to decay (*temporal-delay* hypothesis; Hommel, 1993), thereby reducing spatial conflict. When the perceptual salience of the directional information was increased by presenting the target alone after the background a larger SCE (and a reduced RCE) was observed. However, for eyes alone or embedded in faces, the RCE remained robust across experiments.

Neurophysiological findings further support the distinction between non-social and social mechanisms underlying the effect observed for social targets. Marotta et al. (2019) found that both social and non-social stimuli elicited similar early event-related potential components (P1 and N1) but diverged at later stages (N2 and P3), suggesting commonalities and differences in conflict resolution processes. Complementary functional magnetic resonance results showed overlapping activation in right parieto-

temporo-occipital regions for both arrow and gaze stimuli during conflict resolution, along with distinct activation patterns in the frontal eye field and occipital regions (Narganes-Pineda et al., 2023).

Thus, whereas a general spatial conflict mechanism might be common for social and non-social targets, an additional social mechanism may be induced by social targets, with socially oriented hypotheses proposing these two mechanisms to be distinct. The eye-contact hypothesis proposes that incongruent gaze stimuli (e.g., a left looking gaze presented at the right) are perceived as "looking at" the participants, thereby facilitating responses (Cañadas & Lupiáñez, 2012; Marotta et al., 2018; Ponce et al., 2025a). The joint attention hypothesis posits that incongruent trials align participants' attention with the stimulus direction (joining attention at fixation), thus enhancing response speed (Edwards et al., 2020). Conversely, the joint distraction hypothesis (Hemmerich et al., 2022) suggests that congruent gaze cues (e.g., a left looking gaze presented at the right) may automatically divert attention away from the task space, making it necessary to reorient attention back to the relevant task area, thus slowing RTs.

Support for the social nature of the additional mechanism triggered by social targets includes findings that the RCE is modulated by facial emotion (Jones, 2015; Marotta et al., 2022; Torres-Marín et al., 2017), it is negatively correlated with social anxiety scores for gaze targets but not arrows or words (Ishikawa et al., 2021), and it is influenced by stimulus familiarity (Ishikawa et al., 2024). However, these interpretations have been challenged. Narganes-Pineda et al. (2022) showed that explicit processing of stimulus direction was necessary to elicit the RCE, contradicting the automaticity assumed by the eye-contact hypothesis. The developmental results from Aranda-Martín et al. (2022) also raise questions about the sufficiency of joint attention mechanisms in explaining the RCE, since such mechanisms emerge before age four (Mundy et al., 2007). Additionally, Aranda-Martín et al. (2023) found that adding external objects or frames to reduce distraction in congruent trials did not diminish the RCE, challenging the joint distraction account.

This has led some authors to question the social nature of the additional mechanisms reversing the SCE, by arguing that the RCE might not require any social processing and could rather be explained by perceptual or task-related dynamics alone.

For instance, Chen et al. (2022) found that stimuli with similar perceptual features elicited comparable congruency effects regardless of their social nature. When perceptually simplified, both gaze and arrow stimuli produced an SCE (Experiment 3), whereas more complex stimuli (Experiment 2) showed no significant difference between social and non-social targets, suggesting that stimulus perceivability plays a key role (although see Cañadas & Lupiáñez, 2012).

Tanaka et al. (2024) observed an RCE using tongues as directional stimuli and proposed the dual-stage hypothesis, based on the activation-suppression framework (Ridderinkhof, 2002a, 2002b). According to this model, in the first stage, background segregation delays access to task-relevant information, allowing irrelevant spatial codes to decay (Román-Caballero et al., 2021a; 2021b). In the second stage, selective inhibition acts on the remaining spatial code. If the spatial and directional codes are congruent, inhibition may suppress the correct response, delaying it. In contrast, during incongruent trials, inhibition suppresses the incorrect response code, facilitating the correct response. With simple stimuli like arrows, this mechanism may not engage quickly enough, resulting in the typical SCE. However, if directional information is sufficiently delayed or inhibition strongly activated, even arrows might elicit an RCE.

Nevertheless, it remains unclear whether perceptual difficulty alone is sufficient to produce the RCE. While some studies have shown the RCE with non-social stimuli, its magnitude tends to be smaller and less consistent than the RCE observed with gaze (Román-Caballero et al., 2021a; Tanaka et al., 2025a). In addition, some of those studies used mosaic patterns derived from faces, which might still trigger face-specific processing. As such, the role of perceptual complexity alone in generating the RCE has not been directly tested.

Interestingly, the RCEs elicited by non-social stimuli appear to differ in important ways from those elicited by social stimuli. This difference can be seen from a detailed examination of the temporal dynamics underlying location-based conflict effects (Ponce et al., 2025a, 2025b; Tanaka et al., 2025a, 2025b). Using the conditional accuracy function (CAF), a method that links accuracy to response speed (Heitz, 2014), recent studies have shown that among the fastest responses social stimuli not only lead to lower accuracy for

both congruent and incongruent trials, but also elicit a reversal pattern, with more errors on congruent than incongruent trials (Ponce et al., 2025a).

This effect was especially pronounced for full-face and emotional face stimuli, suggesting that beyond the typical response capture driven by task-irrelevant spatial location (as seen with non-social stimuli; Torres-Quesada et al., 2022; Ridderinkhof, 2002a, 2002b; van Campen et al., 2014, 2018), social targets may activate distinct cognitive mechanisms that modulate early processing stages.

Delta function analyses, which assess how the spatial Stroop effect varies across response latencies (De Jong et al., 1994; Pratte et al., 2010; Speckman et al., 2008), have also shown a distinctive pattern of RCE dynamics in response to social stimuli. The RCE remains consistent from the second quantile onward in a five-point delta function (Ponce et al., 2025b), and across the entire distribution in a four-point delta function (Tanaka et al., 2025a). In contrast, for non-social targets embedded in complex backgrounds, the reversal tends to emerge only in the slower portions of the distribution and with a smaller magnitude (Tanaka et al., 2025a). These findings suggest that gaze stimuli, whether isolated eyes or full-face images, may elicit specific patterns either due to their social nature or their perceptual complexity and configuration.

The present pre-registered study investigated whether the RCE is primarily driven by domain-specific social mechanisms or can also arise from task-related factors, such as difficulty in accessing task-relevant information due to increased visual complexity. Previous research has shown that non-social stimuli can occasionally elicit small RCEs, though typically with weaker and less consistent patterns than those found with social stimuli. Building on these findings, we pre-registered the hypothesis that greater difficulty would weaken the SCE, while additional social features are necessary to fully reverse it (see **Transparency and Openness** section).

To test this hypothesis, we first examined whether a reversal of the spatial Stroop effect could be elicited by perceptual complexity alone, in the absence of social content. Building on Román-Caballero et al. (2021a, 2021b) and Tanaka et al. (2024, 2025a), we manipulated the ease of processing directional information in non-social stimuli (arrows) by overlaying them with different levels of visual noise using overlapping oblique lines acting as a mask, creating three degrees of difficulty (**Figure 1**). This masking

manipulation, conceptually related to techniques used in masked priming studies that often yield the negative compatibility effect (e.g., Eimer & Schlaghecken, 2002), was intended to hinder access to directional information without introducing social features.

We predicted that increasing perceptual difficulty would lead to a gradual reduction in the SCE. However, a full reversal (i.e., an RCE) would only occur with social stimuli. In contrast, if a clear RCE were to be observed with increased perceptual difficulty for non-social stimuli, the social nature of the mechanism producing the RCE observed with gaze would be called into question.

In addition, we examined the temporal dynamics of interference using two distributional analyses: CAF and delta plots. Prior research has shown that increasing perceptual demands, such as through reduced visibility (Mittelstädt & Miller, 2020), added conflicting layers (Scerrati et al., 2017), or decreased discriminability (Ellinghaus et al., 2024), can modulate interference in location-based conflict tasks. Accordingly, we expected to observe changes in conflict dynamics, but not the early accuracy reversal or full RCE typically associated with social stimuli.

Experiment 1

In Experiment 1, we aimed to investigate whether hindering access to task-relevant directional information is sufficient to reduce or eliminate spatial interference, even when using only non-social stimuli (i.e., arrows). To do so, we manipulated perceptual difficulty by masking arrow stimuli with several oblique lines (see **Figure 1**), creating three levels of difficulty. This masking technique was intended to impede the extraction of arrow direction, without introducing background complexity or social content.

For level-1 stimuli, we expected to observe the SCE, as the irrelevant information still impacts on the processing of the relevant directional information. For level-2 stimuli, we predicted a reduction in the SCE compared to level-1, as increased visual noise would hinder directional processing and allow spatial codes to decay or be inhibited. Finally, for level-3 arrows, we expected that spatial interference would be eliminated as task-irrelevant spatial codes should decay or be fully inhibited before response selection.

In the CAF analysis, we expected the typical pattern for level-1 arrows: lower accuracy rates for incongruent trials in the fastest responses, and stable accuracy for congruent trials across the distribution. For level-2 and level-3 arrows, we anticipated an overall reduction in accuracy, particularly in the fastest responses, and no congruency difference in accuracy reflecting increased difficulty in extracting relevant directional information.

In the delta plots analysis, we expected a stronger SCE in the fastest responses, reflecting early interference from irrelevant information that gradually decays or is inhibited over time. For level-2 and level-3 arrows, we expected a similar pattern, larger SCE in the fastest responses, followed by a reduction approaching zero at slower RTs.

Method

Participants

Thirty-four adults (22 females; mean age = 22.4 years, *SD* = 2.9) participated in the study. All were students from the University of Granada who signed an informed consent form. Participants were able to choose between receiving 6 euros or partial course credit for their participation and were naïve to the purpose of the experiment. Data collection took place in June 2024. The study was conducted in accordance with the ethical guidelines of the University of Granada (3232/CEIH/2023) and the 1964 Declaration of Helsinki. Outliers were identified based on mean accuracy scores, with participants excluded if their overall performance fell more than 3 standard deviations below the group mean across conditions.

Sample size was a priori computed based on power analyses conducted using data from Marotta et al. (2018), applying the *Superpower* R package (Lakens & Caldwell, 2021), which enables simulation-based planning for ANOVA designs. Based on data from non-social targets, we ran simulations (10,000 iterations each) to test for the interaction between target type (three levels) and congruency (two levels), aligned with our expected effects (the script and dataset are available in OSF, see **Transparency and Openness** section). With a sample size of 34 and α set at .05, the simulation yielded a power of .81 to detect an effect size of Cohen's $f = 0.16$. Additionally, we conducted a separate power analysis for the congruency effect using arrow stimuli via the *pwr* R package (Champely

et al., 2022). With $N = 34$, $\alpha = .05$, and an expected effect size $d_z = 0.71$, the analysis yielded a power of .99 for a one-sided paired *t*-test. However, for all statistical analyses, including congruency effects for any target type, we employed two-tailed tests to ensure consistency and adopt a more conservative approach, particularly given prior evidence that non-social stimuli can also elicit RCEs (Román-Caballero et al., 2021a; Tanaka et al., 2025a).

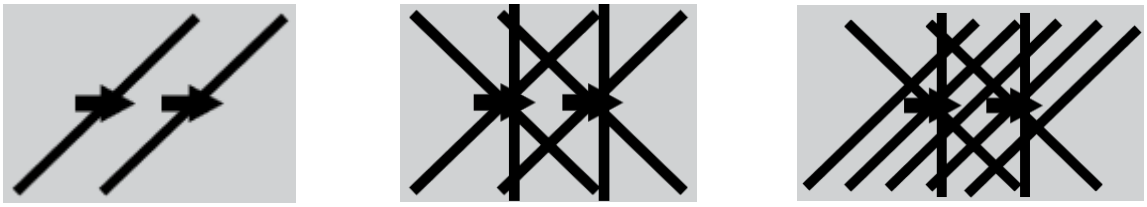
Apparatus and Stimuli

The study was conducted online. The experiment was programmed using *OpenSesame* (Mathot et al., 2012) and administered via *JATOS* (Lange et al., 2015). Arrow stimuli were presented with oblique lines that served as a mask to reduce their perceptual clarity, producing three levels of difficulty (**Figure 1**). To control for any inadvertent directional biases associated with the lines, each mask configuration was also presented in a mirrored version.

Figure 1

Masked Arrows Example

A) B) C)



Note. Examples of target types with three levels of perceptual difficulty: (A) level-1, (B) level-2, and (C) level-3.

Procedure

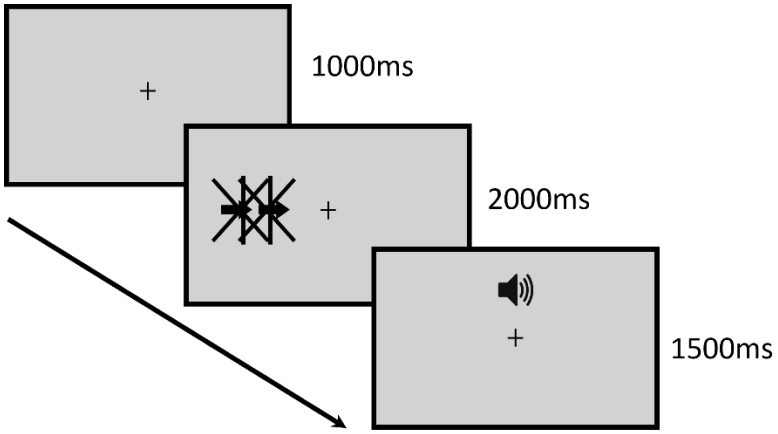
The procedure was adopted from Marotta et al. (2018). Participants first completed 15 practice trials, followed by two experimental blocks of 192 trials each. All three levels of target difficulty were randomly intermixed within each block. Each block included 64 congruent and 64 incongruent trials per target type, yielding a total of 384 experimental trials.

Participants performed a spatial Stroop task in which they were instructed to respond as quickly and accurately as possible to the direction of the arrow (left or right)

while ignoring its spatial location. Each trial began with a central fixation cross (1000 ms), followed by the lateralized arrow target (pointing left or right), which remained onscreen until a response was made or for a maximum of 2000 ms (**Figure 2**). Incorrect responses were followed by auditory feedback lasting 1500 ms. Participants were instructed to fixate on the central cross and to respond using the "C" key for left-pointing arrows and the "M" key for right-pointing arrows, regardless of the stimulus location.

Figure 2

Schematic View of a Trial Sequence



Note. The example represents incongruent trials of the target type level 2. The speaker icon represents the auditory feedback that is provided on incorrect responses.

Design and Statistical Analysis

The study employed a 3 × 2 within-subjects design with two factors: target type (level-1, level-2, level-3 arrows) and congruency (congruent vs. incongruent). Repeated-measures ANOVAs tested the two main effects and their interaction for both RT and accuracy. Given a significant interaction, we conducted paired two-tailed t-tests comparing congruent and incongruent trials within each target type (Bonferroni-corrected). As preregistered, we also computed spatial interference effects (incongruent minus congruent RTs), which were tested against zero and compared across target types.

Conditional Accuracy Function (CAF) analyses were conducted to explore temporal dynamics in performance. RTs were sorted from fastest to slowest and divided into five equal-sized bins (20% each), following procedures from previous studies (e.g., Hübner & Töbel, 2019; Ponce et al., 2025a). Accuracy was calculated per participant within each combination of target type, congruency, and bin, yielding a 3 × 2 × 5

repeated-measures design. Delta function analyses were performed on correct responses using quantile averaging (Ratcliff, 1979). RT quantiles were estimated using R's quantile function with the type 8 estimator (Hyndman & Fan, 1996) at the following probabilities: .1, .3, .5, .7, and .9 (e.g., Grange, 2016; Ponce et al., 2025b). Delta values were calculated as the difference between RTs on incongruent and congruent trials at each quantile. This yielded a 3 × 5 design (target type × quantile). For both CAF and delta function analyses, repeated-measures ANOVAs tested for main effects and interactions. Additional paired t-tests (Bonferroni-corrected) compared congruency levels within each CAF bin by target type and assessed differences in delta values across target types and quantiles. One-sample t-tests were also used to determine whether delta values at each quantile significantly differed from zero.

Transparency and Openness

We reported how we determined our sample size, all data exclusions, manipulations, and measures. All hypotheses, experimental design, and analysis plans were preregistered prior to data collection. The preregistrations, along with task materials, stimuli, datasets, and analysis scripts, are publicly available on the Open Science Framework (OSF) at https://osf.io/yvcak/.

Results and Discussion

Practice trials were excluded from all analyses. Following the procedure used by Marotta et al. (2018), trials with RTs below 200ms (0.05%) or above 1300 ms (1.86%), together with incorrect responses (5.30%), were excluded from the RT analysis. The same trimming procedure was applied to the distributional analyses. Greenhouse–Geisser (GG) corrections were applied when the assumption of sphericity was violated. **Table 1** shows mean RTs and percentage of incorrect responses by condition.

Table 1.

Mean RT in Milliseconds and Percentages of Incorrect Responses (IR) by Condition and Experiment

		Experiment 1		Experiment 2			
				within		between	
		congruent	incongruent	congruent	incongruent	congruent	incongruent
Arrows Level1	RT	547 (79)	569 (88)	557 (106)	571 (106)	517 (87)	547 (101)
	% IR	1.11 (1.42)	4.16 (5.52)	2.21 (2.73)	4.81 (4.69)	3.13 (3.06)	8.24 (6.19)
Arrows Level2	RT	603 (69)	588 (84)	616 (104)	596 (110)	587 (73)	570 (81)
	% IR	5.85 (6.62)	4.53 (5.94)	7.68 (5.34)	6.84 (6.50)	7.42 (6.59)	6.25 (6.91)
Arrows Level3	RT	633 (77)	619 (81)	641 (100)	621 (105)	607 (76)	588 (76)
	% IR	6.68 (9.56)	5.53 (6.04)	11.17 (8.54)	8.01 (6.60)	8.72 (8.09)	6.25 (6.22)
Gaze	RT	-	-	646 (105)	626 (109)	582 (91)	578 (96)
	%IR	-	-	5.44 (4.99)	5.34 (5.53)	4.33 (4.57)	7.26 (7.42)

Note. Standard deviations of RTs and IRs are reported in parentheses.

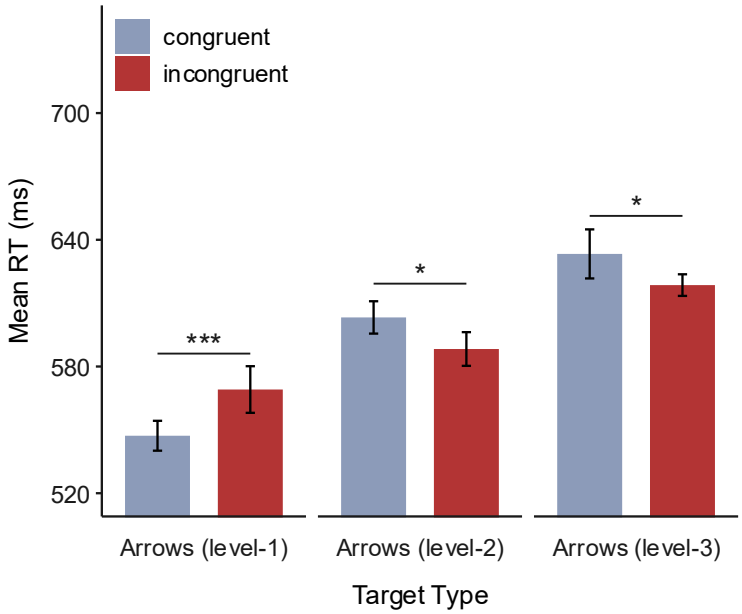
Reaction Time

The ANOVA on RTs revealed a main effect of target type, $F(1.55, 51.11) = 115.04$, $p < .001$, $\eta_p^2 = .78$. Participants responded fastest to level-1 arrows (558 ms), followed by level-2 (596 ms), and level-3 arrows (626 ms). All pairwise comparisons between the three levels were significant (all ps < .050).

Critically, there was a significant interaction between target type and congruency, $F(2, 66) = 22.23$, $p < .001$, $\eta_p^2 = .40$. Follow-up analyses revealed an SCE for level-1 arrows, $t(33) = -3.84$, $p < .001$, $d_z = -0.66$, with faster responses in congruent than incongruent trials, and an RCE for both level-2, $t(33) = 2.47$, $p = .019$, $d_z = 0.42$, and level-3 arrows, $t(33) = 2.53$, $p = .016$, $d_z = 0.43$, with faster responses for incongruent than congruent trials (**Figure 3**). The congruency effect did not differ significantly between level-2 (−15 ms) and level-3 (−15 ms) arrows, but both differed significantly from level-1 arrows (22 ms; see **Supplemental Material**).

Figure 3

Mean RTs by Congruency for Each Target Type



Note. Blue-purple bars correspond to congruent trials and red bars to incongruent trials. Error bars represent 95% confidence intervals, adjusted using the Cousineau-Morey method (Morey, 2008). Asterisks indicate significance levels: *$p < .05$, **$p < .01$, *** $p < .001$.

Accuracy

The accuracy analysis revealed a main effect of target type, $F(2, 66) = 10.04$, $p < .001$, $\eta_p^2 = .23$. Error rates were lower for level-1 arrows (2.63%) than for level-2 (5.19%) and level-3 (6.11%) arrows, with no significant differences between the latter two.

The interaction between target type and congruency was also significant, $F(1.65, 54.45) = 7.20$, $p = .003$, $\eta_p^2 = .18$. Pairwise comparisons revealed that level-1 arrows elicited fewer errors on congruent than on incongruent trials (**Table 1**), $t(33) = 3.08$, $p = .004$, $d_z = 0.53$. No other congruency effects reached significance.

Distribution Analysis

CAF analyses revealed a significant three-way interaction among target type, congruency, and bin, $F(3.70, 122.08) = 3.02$, $p = .023$, $\eta_p^2 = .08$. For the fastest RT bin, only level-1 arrows showed a congruency effect, $t(33) = 2.97$, $p = .006$, $d_z = 0.51$, with more errors on incongruent than congruent trials. Additionally, for level-1 arrows, accuracy in the first bin was lower than in bins two and three. Although the differences between

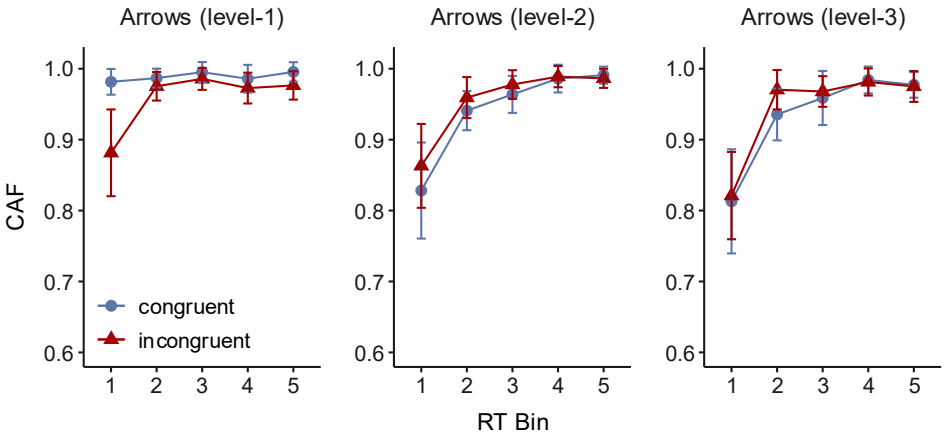
congruent and incongruent trials reversed in sign (i.e., more errors for congruent than incongruent trials) for level-2 and level-3 arrows, these differences were not significant. However, both the level-2 and level-3 conditions showed reduced accuracy in the first bin, regardless of congruency, compared to later bins (**Figure 4A**).

Delta function analysis revealed a main effect of target type, $F(2.00, 66.0) = 20.15$, $p < .001$, $\eta_p^2 = .38$. Planned one-sample *t*-tests against zero showed that level-1 arrows exhibited an SCE across the RT distribution, with the exception of the fifth quantile ($p = 0.058$). In contrast, the RCE for level-2 and level-3 arrows emerged primarily in the mid-range quantiles: the third and fourth quantiles for level-2 arrows and the second and third quantiles for level-3 arrows (**Figure 4B**). The remaining quantiles did not significantly differ from zero. Additionally, the RCE increased across quantiles only for level-2 arrows, peaking at the third quantile (i.e., larger effect at the third compared to the first quantile); no other quantile-related effects were observed for the remaining target types.

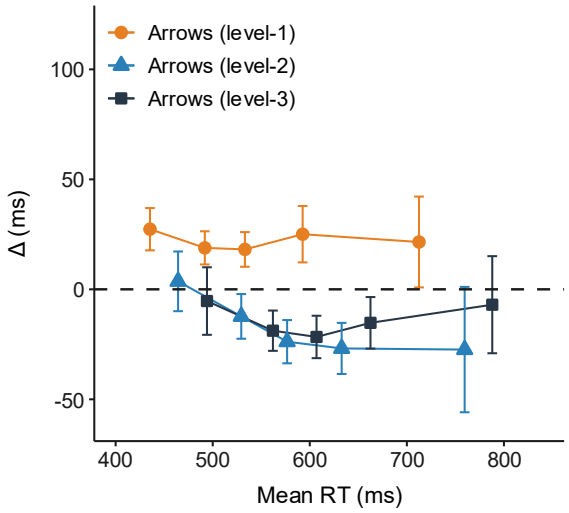
Figure 4

Distributional Analysis from Experiment 1

A)



B)



Note. Panel (A) shows CAFs (accuracy across RT bins for congruent and incongruent trials, by target type). Blue-purple points indicate congruent trials, and red triangles indicate incongruent trials. Panel (B) shows delta plots (RT differences between incongruent and congruent trials across mean RT quantiles). Orange circles represent level-1 arrows, light-blue triangles level-2 arrows, and dark-blue squares level-3 arrows. Error bars represent 95% confidence intervals, adjusted using the Cousineau–Morey method (Morey, 2008).

Discussion

Experiment 1 investigated whether increased perceptual difficulty in non-social stimuli (i.e., arrows) could modulate or reverse the spatial congruency effect (SCE), commonly observed in location-based conflict tasks. The results provide compelling

evidence that, contrary to our hypotheses, the perceptual manipulation alone—without social content—can significantly alter the direction of congruency effects, including the emergence of a reversed congruency effect (RCE). As predicted, level-1 arrows elicited a robust SCE, with faster and more accurate responses in congruent compared to incongruent trials. This pattern replicates the classical Stroop effect generally observed in spatial interference tasks. In contrast, level-2 and level-3 arrows revealed a significant RCE with participants responding faster to incongruent than congruent trials. This finding challenges our initial hypothesis that a social component is necessary to elicit the RCE and supports the view that hindering the processing of task-relevant information can be enough to produce the effect.

Distributional analyses further confirmed this interpretation. CAF plots revealed that the SCE in level-1 arrows was strongest among the fastest responses, consistent with early response capture by irrelevant spatial information. For level-2 and level-3 arrows, the CAF analyses showed reduced accuracy in the fastest bin for both congruent and incongruent trials, consistent with prior findings with social stimuli (Ponce et al., 2025a). However, in contrast to what usually happens with gaze targets, no clear reversal in accuracy was observed within the first bins. Overall, the pattern suggests that increased perceptual complexity interferes with early information extraction.

Delta function analyses reinforce this interpretation: while level-1 arrows exhibited a SCE across most of the RT distribution, levels 2 and 3 showed an RCE that peaked in the mid-range quantiles. Notably, no SCE appeared for levels 2 and 3 at any point across the distribution, contrasting with previous studies using complex backgrounds to induce RCEs in non-social targets (Tanaka et al., 2025a). These results suggest that the RCE observed with masked arrows might be more robust than that induced by background complexity.

Overall, our findings show that while social targets may modulate the magnitude and pattern of the RCE (Ponce et al., 2025b; Tanaka et al., 2025a), they are not essential for its emergence. Simply increasing perceptual noise that impairs access to directional information seems sufficient to produce an RCE, supporting non-social accounts (Tanaka et al., 2024, 2025a). However, the conflict effects and dynamics of the RCE may differ

between social and non-social targets. We directly compared these in the next experiment.

An alternative possibility is that the RCE elicited by masked arrows may reflect not just perceptual difficulty, but a global strategic adjustment adopted by participants in response to how the task was structured (Ellinghaus et al., 2024; Hübner & Mishra, 2013). Prior research has shown that people can adapt their cognitive control depending on task demands and expectations (Banich, 2019; Braver, 2012; Spinelli et al., 2022). For instance, Hübner and Mishra (2013) proposed that participants modulated the suppression of task-irrelevant information (i.e., location of the stimuli) depending on predictability. When task conditions varied unpredictably (i.e., randomized blocks), stronger suppression is required to maintain performance, resulting in smaller interference effects. In contrast, under more predictable conditions (i.e., blocked designs), less suppression is sufficient to achieve comparable performance.

In Experiment 1, all levels of stimulus perceptual difficulty were randomly intermixed within the same block. This unpredictability may have encouraged participants to adopt a global suppression strategy, reducing the influence of irrelevant location information. Such a strategy could have contributed to the RCE, alongside the effects of perceptual masking. Notably, strategic adaptation and perceptual complexity explanations are not mutually exclusive. However, to better understand the role of perceptual complexity, it is necessary to test whether it alone can produce the RCE, independent of strategic factors.

Experiment 2

The goal of Experiment 2 also preregistered (see **Transparency and Openness** section), was to test the robustness of the results from Experiment 1 and to directly compare spatial interference effects elicited by arrow and gaze stimuli. Additionally, following the rationale of Hübner and Mishra (2013), we manipulated stimulus predictability to examine whether participants adjust their inhibitory strategies based on the consistency of target presentation. To this end, we included both masked arrow targets as in Experiment 1, as well as gaze targets, and assigned participants to one of two experimental groups: (1) a within-block group in which all target types (level-1 arrows,

level-2 arrows, level-3 arrows, and gaze) were intermixed (as in Experiment 1), and (2) a between-block group, in which each target type was presented in separate blocks.

Considering the pattern of results observed in Experiment 1, we pre-registered the hypothesis that level-1 arrows would elicit an SCE, while level-2 and level-3 arrows, as well as gaze stimuli, would produce an RCE. Moreover, we expected these effects to interact with stimulus presentation sequence. In the within-block condition, where target type is less predictable, we anticipated stronger suppression of irrelevant location codes, leading to reduced SCEs and enhanced RCEs (Román-Caballero et al., 2021a, 2021b). Conversely, in the between-block condition, reduced suppression was expected to yield larger SCEs and diminished RCEs.

At the distributional level, we expected the within-block group to replicate the pattern observed in Experiment 1. In contrast, the between-block group was expected to show larger SCEs (i.e., weaker suppression) and a reduced RCE, particularly in the earliest response bins of the CAF, where such modulations typically emerge (Ponce et al., 2025a), and across the response distribution in the delta plots.

Method

Participants

Ninety-six participants took part in the study, with 48 randomly assigned to each group. The within-block group included 46 females (mean age = 20.3, *SD* = 2.4), and the between-block group included 43 females (mean age = 20.6, *SD* = 2.7). All participants were undergraduate students at the University of Granada and received partial course credit for their involvement. Data collection took place between October and November 2024. The study adhered to the same ethical standards as Experiment 1. Participants with mean accuracy more than 3 SDs below the group mean were excluded as outliers.

The sample size was a priori determined to allow full counterbalancing in the between-block condition. With four target types, block-order counterbalancing required 24 sequences, each assigned to two participants. A power analysis was conducted based on data from Román-Caballero et al. (2021a, Experiment 1), which reported a relatively small RCE for arrows presented against complex backgrounds. Using the *Superpower* R package (Lakens & Caldwell, 2021), we simulated 10000 iterations to estimate the power

for the interaction between target type and congruency. Results indicated that a sample size of 35 participants would yield .80 power to detect a medium effect (Cohen's $f = 0.20$, $\alpha = .05$). With 48 participants per group, our estimated power increased to .91. The full analysis script and dataset are available via OSF.

Apparatus and Stimuli

The experiment was conducted online using *JATOS* (Lange et al., 2015) and programmed in *OpenSesame* (Mathot et al., 2021). The task structure was identical to Experiment 1, with the addition of social stimuli and the group division (within block vs. between-block). Gaze targets consisted of color photographs of four female and four male faces with neutral expression, looking either left or right. Images were taken from the Karonliska Directed Emotional Faces database (Lundqvist et al., 1998), the same source used in Marotta et al. (2022). Each gaze stimulus was cropped into a rectangular frame, with the eyes horizontally centered and vertically aligned to match the position of the arrows and overlapping lines (**Figure 5**).

Figure 5

Masked Arrows and Gaze Stimuli

A) B)

Note. Examples of A) level-3 arrow stimuli and B) gaze stimuli.

Procedure

The structure and number of trials by condition were identical to those used in Experiment 1, with the exception that this experiment was divided into four blocks separated by brief breaks. In the between-block group, each block presented a single target type, and block order was counterbalanced across participants. In the within-block group, all target types were randomly intermixed within each block.

Design and Statistical Analysis

Experiment 2 employed a 2 × 4 × 2 mixed design, with group (within-block vs. between-block) as the between-subjects factor, and target type (level-1 vs. level-2 vs. level-3 vs. gaze) and congruency (congruent vs. incongruent) as within-subject factors. Trimming procedures were the same as those used in Experiment 1. Distributional analyses (CAF and delta functions) were conducted using the same approach as in Experiment 1, with the addition of the group factor.

For the sake of clarity, only the results relevant to our primary research questions are reported below. Additional preregistered analyses are provided in the **Supplemental Material**.

Transparency and Openness

Transparency and openness procedures followed those described in Experiment 1. All preregistrations, materials, data, and analysis scripts are available at https://osf.io/yvcak/.

Results and Discussion

Trimmed responses were excluded from the RT and distributional analyses. In the within-block group, 0.10% of trials were faster than 200 ms and 2.55% were slower than 1300 ms. In the between-block group, 0.10% of trials were also faster than 200 ms, with 1.16% slower than 1300 ms. Incorrect responses were excluded from the RT analyses: 6.44% for the within-block group and 6.45% for the between-block group (**Table 1**).

Reaction Time

A significant main effect of target type was observed, $F(3, 282) = 115.81$, $p < .001$, $\eta_p^2 = .55$. Although responses to level-3 arrows (615 ms) and gaze stimuli (608 ms) did not significantly differ, both were slower than responses to level-2 arrows (592 ms) and level-1 arrows (548 ms), with level-2 arrows also significantly slower than level-1 arrows. The main effect of group was also significant, $F(1, 94) = 4.02$, $p = .048$, $\eta_p^2 = .04$, with slower overall responses in the within-block group (609 ms) compared to the between-block group (572 ms). This group difference was further evident in a significant group × target type interaction, $F(3, 282) = 5.20$, $p = .002$, $\eta_p^2 = .05$. Follow-up analyses showed that

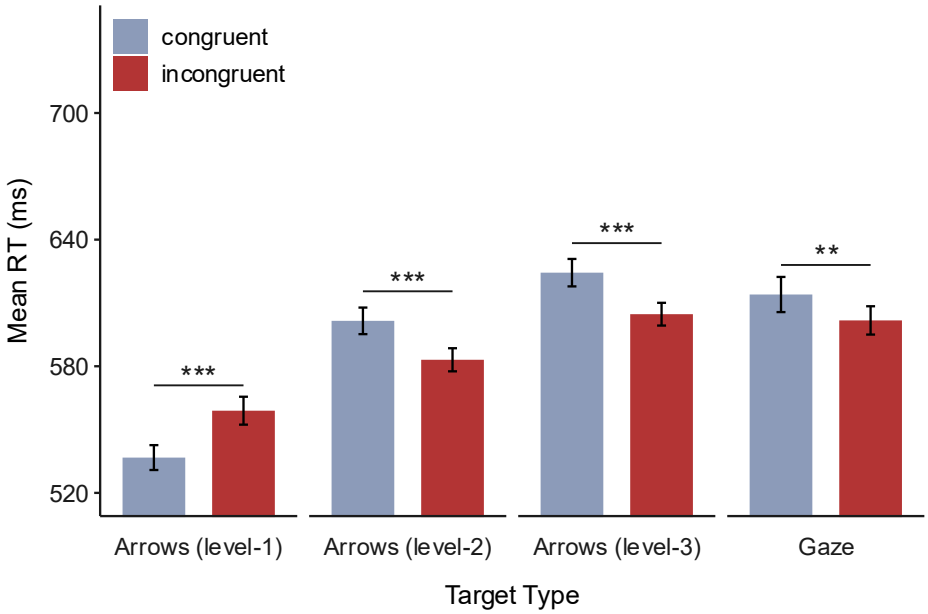
within-block participants responded more slowly than between-block participants for all target types. Moreover, pairwise comparisons within each group showed that in the within-block group, RTs increased from level-1 to level-2 and level-3 arrows, with gaze stimuli not differing from level-3 arrows but slower than level-1 and level-2. In the between-block group, a similar stepwise increase was observed, but here gaze stimuli were significantly faster than level-3 arrows and did not differ from level-2 arrows.

The three-way interaction between group, target type, and congruency was not significant, $F(3, 282) = 1.90$, $p = .129$, $\eta_p^2 = .02$. However, and more importantly. a significant target type × congruency interaction emerged, $F(3, 282) = 42.30$, $p < .001$, $\eta_p^2 = .31$. Consequently, the contrast analyses reported below were conducted across groups.

Replicating the pattern observed in Experiment 1, level-1 arrows elicited an SCE, with faster responses on congruent than incongruent trials (**Figure 6**), $t(95) = -6.78$, $p < .001$, $d_z = -0.69$. In contrast, level-2 and level-3 arrows produced an RCE, $t(95) = 5.36$, $p < .001$, $d_z = 0.55$, $t(95) = 6.37$, $p < .001$, $d_z = 0.65$, respectively. Gaze stimuli also elicited a significant RCE, $t(95) = 2.84$, $p = .006$, $d_z = 0.29$.

Figure 6

Mean RTs (in milliseconds) by congruency for each target type



Note. As the interaction between group, target type, and congruency was not significant data were collapsed across groups for visualization purposes. Blue-purple bars correspond to congruent trials and red bars to incongruent trials. Error bars represent 95% confidence intervals, adjusted using the Cousineau–Morey method (Morey, 2008). Asterisks indicate significance levels: *p < .05, **p < .01, *** p < .001.

Regarding the spatial Stroop effect, analyses of Stroop interference scores showed that the group × target type interaction was not significant. However, both the main effect of group and the main effect of target type were significant. Consistent with our hypothesis, the within-block group showed a larger RCE (−12 ms) than the between-block group (−2 ms). Notably, the RCEs for level-2 arrows (−18 ms), level-3 arrows (−20 ms), and gaze targets (−12 ms) did not significantly differ from one another (although see **Supplemental Material** for results on gaze targets when analyzed separately by group), but all significantly differed from the SCE observed for level-1 arrows (22 ms).

Accuracy

A significant main effect of target type was observed, $F(2.55, 239.24) = 29.67$, $p < .001$, $\eta_p^2 = .24$. Error rates were lowest for level-1 arrows (4.60%), followed by gaze (5.59%), level-2 arrows (7.05%), and level-3 arrows (8.54%). Gaze stimuli did not significantly differ from level-1 arrows but showed significantly lower error rates than level-2 and level-3 arrows. A significant interaction between group and target type was

also found, $F(2.55, 239.24) = 7.89$, $p < .001$, $\eta_p^2 = .08$, driven by reduced error rates for level-1 arrows in the within-block group.

The three-way interaction between group, target type, and congruency was not significant. However, the interaction between target type and congruency was significant, $F(2.76, 259.33) = 25.09$, $p < .001$, $\eta_p^2 = .21$. Pairwise comparisons revealed that level-1 arrows elicited fewer errors on congruent (2.67%) than incongruent trials (6.53%), $t(95) = 7.57$, $p < .001$, $d_z = 0.77$. In a similar direction, gaze reached a marginal significant result, $t(95) = 1.98$, $p = .050$, $d_z = 0.20$, with fewer errors on congruent (4.88%) than incongruent trials (6.30%). In contrast, level-3 arrows showed the opposite pattern, with fewer errors on incongruent (7.13%) than on congruent trials (9.94%), $t(95) = -3.75$, $p < .001$, $d_z = -0.38$.

Distribution Analysis

Interestingly, the CAF analyses revealed a significant four-way interaction between group, target type, congruency and bin (Figure 7A), $F(6.10, 573.27) = 3.25$, $p = .004$, $\eta_p^2 = .03$. Follow-up analyses showed that level-1 arrows elicited the typical pattern in the fastest responses, with lower accuracy on incongruent than congruent trials in both the within-block group, $t(47) = 3.57$, $p < .001$, $d_z = 0.52$, and between-block group, $t(47) = 2.97$, $p < .001$, $d_z = 1.02$. The between-block group showed a larger congruency effect at this portion of the distribution, as indicated by the Cohen's d values. The RCE was observed in bin 2 for level-2 arrows in the within-block group, $t(47) = -3.40$, $p = .001$, $d_z = -0.49$, and for level-3 arrows in both the within-block group, $t(47) = -3.49$, $p = .001$, $d_z = -0.50$, and between-block group, $t(47) = -2.98$, $p = .005$, $d_z = -0.43$. Notably, gaze targets elicited an SCE in the first bin for the between-block group, $t(47) = 3.59$, $p < .001$, $d_z = 0.52$, and an RCE in the third bin for the within-block group, $t(47) = -2.20$, $p = .033$, $d_z = -0.32$.

Across bins, level-1 arrows showed reduced accuracy on incongruent trials in the first bin, especially in the between-block group. In contrast, replicating Experiment 1, level-2 and level-3 arrows showed reduced accuracy for both congruent and incongruent trials in the fastest responses. Gaze targets displayed a similar but weaker pattern, with lower accuracy in the first bin for both congruent and incongruent trials in both groups.

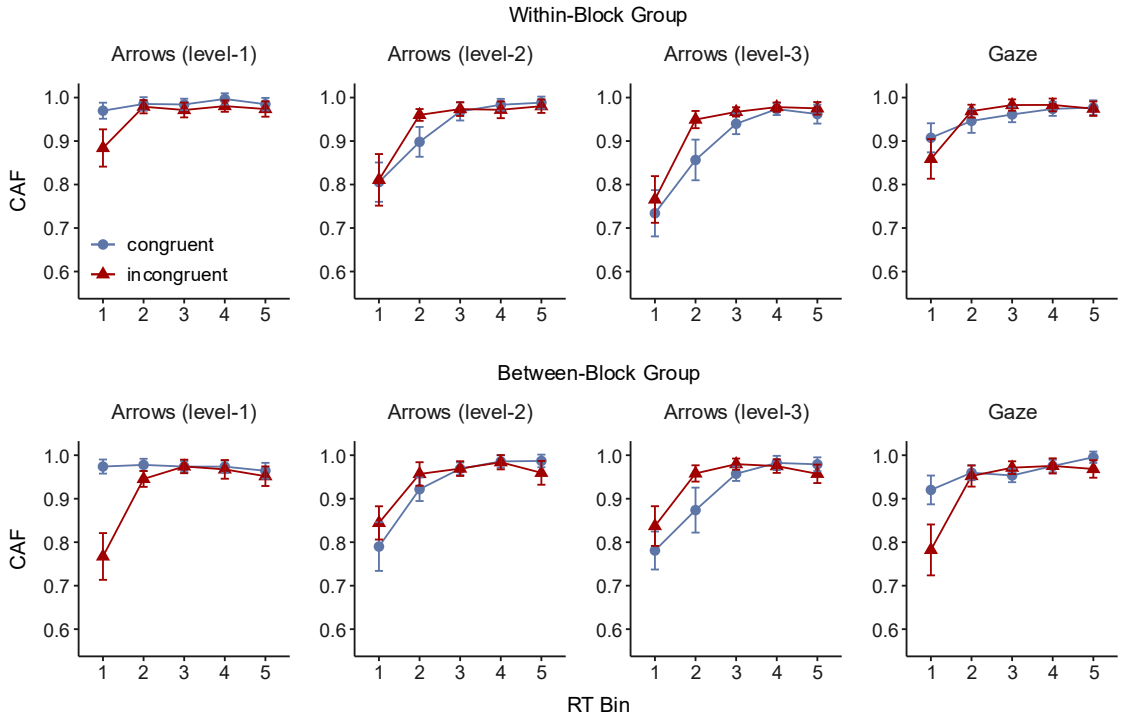
Delta function analysis revealed no significant three-way interaction but did show a significant two-way interaction between target type and quantile (Figure 7B), F(5.34,

501.70) = 5.19, $p < .001$, $\eta_p^2 = .05$. Further analyses indicated that level-1 arrows elicited an SCE across the entire distribution. Both level-2 and level-3 arrows consistently produced an RCE across quantiles, although the effect was attenuated in the first quantile, where level-2 arrows showed no significant difference against zero. Conversely, gaze stimuli, elicited an SCE in the first quantile, with the RCE emerging from the third to the fifth quantile.

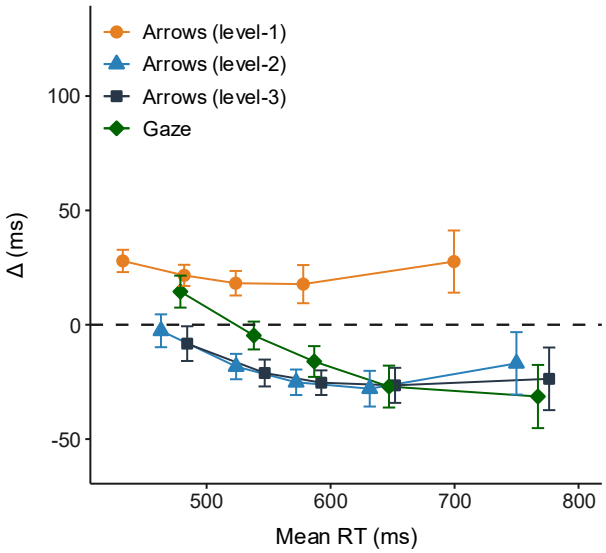
Figure 7

Distributional analysis from Experiment 2

A)



B)



Note. Panel (A) shows CAFs (accuracy across RT bins for congruent and incongruent trials, by target type). Blue-purple points indicate congruent trials, and red triangles indicate incongruent trials. Panel (B) shows delta plots (RT differences between incongruent and congruent trials across mean RT quantiles). As the three-way interaction between group, target type, and quantile was not significant, data in Panel B were collapsed across groups for visualization purposes (see Supplemental Material for the delta plots separated by group). Orange circles represent level-1 arrows, light-blue triangles level-2 arrows, dark-blue squares level-3 arrows, and green diamonds gaze. Error bars represent 95% confidence intervals, adjusted using the Cousineau–Morey method (Morey, 2008).

In addition, to control for potential changes in conflict strength over time or due to block order, we performed complementary analyses on block structure (Supplemental Material). In the within-block group, a repeated-measures ANOVA with block (1–4) and target type as within-subject factors revealed no significant block × target type interaction, indicating that the Stroop effect remained stable across blocks and the strategy adopted by the participants might be initiated from the point of the first few trials. Similarly, in the between-block group, a mixed-design ANOVA with target type (within-subjects) and gaze block position (between-subjects) showed no significant interaction, suggesting that the position of the gaze block within the task did not influence the magnitude of the Stroop effect.

Discussion

Experiment 2 replicated the patterns observed in Experiment 1 for non-social targets: level-1 arrows elicited an SCE, while level-2 and level-3 arrows produced an RCE. At the distributional level, the RCEs for level-2 and level-3 arrows resembled those previously reported for social stimuli, both in CAF analyses, with higher error rates for congruent than incongruent trials at certain points of the distribution, and in reduced accuracy for both congruency conditions among the fastest responses (Ponce et al., 2025a). Similarly, the delta function analyses revealed a pattern consistent with that previously reported for social stimuli, with the reversal of the congruency effect emerging at mid-to-slower response latencies (Ponce et al., 2025b; Tanaka et al., 2025a).

These findings further support the view that a social component is not required to elicit the RCE (Chen et al., 2022; Tanaka et al., 2024, 2025a). Instead, the critical factor

appears to be the difficulty in extracting task-relevant information. Prior work has shown that manipulating target discriminability affects the processing of both relevant (directional) and irrelevant (spatial) information in location-based tasks (Ellinghaus et al., 2024; Mittelstädt & Miller, 2020), supporting the idea that perceptual difficulty can indeed modulate conflict processing. Building on this prior work, our results suggest that when processing of directional information is hindered, the RCE is more likely to emerge.

Nonetheless, not all forms of perceptual interference reliably produce a robust RCE. For example, background segregation manipulations, such as embedding arrows in complex backgrounds, have yielded mixed results. In Román-Caballero et al. (2021a), an RCE was observed when arrows were presented directly on a complex background. However, in their second experiment, the addition of white ovals around the arrows (while keeping the same background) likely made the directional information easier to extract and therefore produced no reversal of the congruency effect. Similarly, no RCE was observed in Román-Caballero et al. (2021b) or Tanaka et al. (2024, Experiment 3), where arrows were embedded in pixeled or mosaic textures. From a distributional perspective, Tanaka et al. (2025a, Supplemental Material) reported no overall RCE with arrows embedded in mosaic backgrounds, although isolated quantiles showed a significant reversal.

Taken together, these findings suggest that background segregation alone may be insufficient to elicit the RCE. Instead, the presence of noisy, overlapping features, such as masking lines used in the present study, appears more effective in triggering the mechanisms underlying the effect. Such manipulations likely engage a combination of task-related processes, including enhanced response capture (Ponce et al., 2025a; 2025b), delayed extraction of directional information (Román-Caballero et al., 2021a, 2021b; Tanaka et al., 2025a), and adjustments to the strength and timing of inhibition (Ponce et al., 2025b; Tanaka et al., 2024, 2025a). These dynamics have been broadly linked to conflict modulation in location-based tasks (Ellinghaus et al., 2024; Luo & Proctor, 2017, 2019; Miller & Schwarz, 2021; Mittelstädt et al., 2023a; Mittelstädt & Miller, 2020; Ridderinkhof, 2002a, 2002b; van Campen et al., 2014, 2018), and their interplay may provide a more specific account of how and when the RCE occurs in the spatial Stroop paradigm (see **General Discussion**).

Regarding the group factor, it influenced performance by modulating overall response latencies and accuracy rates, and the Stroop effect was less negative for the between-block manipulation. Thus, several findings aligned with our expectations. For level-1 arrows, the within-block group showed a reduced SCE, evident in both the overall Stroop effect and the earliest parts of the distribution (i.e., first CAF bin and delta quantile). Follow-up comparisons confirmed that this group-related modulation was specific to level-1 arrows, with no significant differences observed for other non-social targets (see **Supplemental Material**). These findings are consistent with prior work showing reduced interference for easy-to-discriminate stimuli in trialwise (i.e., within-block) designs (Ellinghaus et al., 2024).

For social targets, gaze stimuli elicited an RCE, as expected, and did not significantly differ from other targets in overall Stroop interference. However, a group-level analysis revealed that the RCE was reduced, and not significantly different from zero, in the between-block group (see **Supplemental Material**). Distributional analyses further highlighted differences in conflict dynamics. A significant target type × quantile interaction emerged when gaze stimuli were included—unlike in Experiment 1—suggesting different temporal dynamics of conflict processing for social targets. The main difference observed was the SCE at the first quantile in the delta plot, resembling early effects seen with arrows in complex backgrounds (Tanaka et al., 2025a). Nevertheless, this early SCE was specific to the between-block group, whereas the within-block group showed no such effect (see **Supplemental Material**), replicating prior findings with social stimuli (Ponce et al., 2025b). CAF analyses revealed a complementary dissociation: only the within-block group showed an RCE, although limited to a single bin, replicating patterns previously observed with cropped eyes rather than full-face stimuli (Ponce et al., 2025a). In contrast, the between-block group showed no reversal of the congruent effect.

Interestingly, these group-related differences seem limited to level-1 arrows and gaze targets. One possible explanation is that gaze stimuli used here (cropped faces within a rectangular frame) fall somewhere between level-1 and level-2 arrows in terms of the ease of extracting relevant information, aligning with findings from Ellinghaus et al. (2024) involving easy-to-discriminate stimuli. Supporting this idea, both level-1 arrows and gaze showed lower error rates than the other targets. In both cases, an SCE was

observed in terms of accuracy, with gaze marginally reaching a significant result. Furthermore, contrast analyses on the significant three-way interaction between group, target type, and bin (see **Supplemental Material, Figure 2**) revealed the same accuracy hierarchy in the fastest responses: highest for level-1 arrows, followed by gaze, then level-2 and level-3 arrows.

Taken together, these findings suggest that stimuli offering clearer access to task-relevant information (i.e., level-1 arrows and gaze) may be more sensitive to the demands of trial structure, particularly when target type varies unpredictably (Ellinghaus et al., 2024). In line with Hübner and Mishra's (2013) proposal, our results imply that trialwise presentation (within-block) requires greater suppression of irrelevant information to maintain performance, whereas blocked conditions may allow for more selective preparatory control. This interpretation aligns with broader accounts that emphasize the flexibility of inhibitory mechanisms to adapt their onset and strength depending on task demands (De Jong et al., 1994; Mittelstädt et al., 2023a; Ridderinkhof, 2002a, 2002b).

On a broader level, gaze stimuli have shown distinct patterns in previous studies (Ponce et al., 2025b; Tanaka et al., 2025a), suggesting that the temporal dynamics underlying "social RCEs" may be further modulated by a uniquely social mechanism, such as the looking vector. This concept has been proposed to influence interference effects in response to social targets (Hemmerich et al., 2022; Ponce et al., 2025a, 2025b). Supporting this idea, prior research has demonstrated the impact of gaze across multiple stages of cognitive processing (Emery, 2000; Gobbini & Haxby, 2007; Kobayashi & Kohshima, 1997), which include the triggering of automatic attentional orienting (Driver et al., 1999; Ulloa et al., 2018). These mechanisms may introduce additional modulations to conflict effects, contributing to the patterns observed with social stimuli.

However, fully disentangling the modulatory role of gaze within the RCEs lies beyond the scope of the current study. Future research will be needed to determine which aspects of these effects reflect mechanisms specific to gaze processing or to masking effects. Such investigations could help position social stimuli along a continuum of task-relevant feature accessibility, with full faces potentially representing the most perceptually complex, and thus eliciting the largest RCEs in both CAF and delta function

analyses. In this manner, future studies on this nature would clarify the specific contribution of gaze-related dynamics within the spatial Stroop paradigm.

General Discussion

In social attention research, a recurring finding in spatial Stroop tasks is that social stimuli, such as faces or isolated eyes, often reverse the typical congruency pattern: instead of responding faster to congruent trials (as commonly seen with arrows), participants respond more quickly to incongruent ones, producing the RCE (Cañadas & Lupiáñez, 2012; Marotta et al., 2018). This phenomenon has been attributed to unique interference dynamics introduced by social content, which may override the typical spatial processing mechanisms (Edwards et al., 2020; Hemmerich et al., 2022; Marotta et al., 2018).

As outlined in the introduction, several studies highlight robust dissociations between social and non-social targets (Aranda-Martín et al., 2022; Marotta et al., 2019; Narganes-Pineda et al., 2022, 2023; Román-Caballero et al., 2021a, 2021b), supporting the idea that RCE arises from mechanisms specifically engaged by social stimuli. However, more recent research has begun to question this view by examining whether non-social directional targets can also elicit RCEs under specific perceptual constraints (Chen et al., 2022; Tanaka et al., 2024).

When processing of task-relevant information was hindered, such as by increasing visual complexity (e.g., Román-Caballero et al., 2021a), non-social stimuli occasionally elicited similar congruency effect reversals, although these effects typically have been smaller in magnitude or limited to certain portions of the response distribution (Román-Caballero et al., 2021a; Tanaka et al., 2025a). These findings suggest that the RCE may not be exclusive to social processing, but could instead reflect more general processing constraints related to the accessibility of task-relevant information.

The present study directly tested this hypothesis by manipulating how easily directional information could be extracted from non-social targets. Specifically, arrow stimuli were masked with different levels of visual noise using oblique lines, gradually increasing the difficulty of identifying their direction.

This manipulation reliably and consistently elicited an RCE at the two highest levels of perceptual difficulty, reinforcing the idea that the accessibility of task-relevant features plays a central role in the emergence of the reversal pattern. In doing so, our findings bridge social and non-social accounts by identifying perceptual difficulty as a shared mechanism underlying the RCE.

Beyond highlighting the unique role of perceptual difficulty, our results also align with prior work emphasizing the complex temporal dynamics of this phenomenon. Studies using CAF and delta function analyses suggest that complex stimuli engage multiple processes, including modulations in response capture (Ponce et al., 2025a), changes in the relative speed of task-relevant and -irrelevant information processing, and adjustments to the strength and onset timing of inhibition (Ponce et al., 2025b; Tanaka et al., 2024, 2025a). Together, our results and these prior findings support the idea that the RCE reflects not a singular mechanism, but an interaction among stimulus complexity, temporal dynamics, and cognitive control.

These dynamics have been widely characterized within the dual-route framework, a theoretical applied account of conflict processing (Hübner & Töbel, 2019; Kelber et al., 2025; Luo & Proctor, 2017; Mittelstädt et al., 2022), and formalized through computational models (Luo & Proctor, 2022; Schwarz & Miller, 2012; Ulrich et al., 2015). According to this framework, interference arises from the interplay between a controlled route, which processes task-relevant information according to instructions, and an automatic route, which reflexively activates responses based on task-irrelevant attributes like spatial location (Cohen et al., 1990; De Jong et al., 1994; Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015).

The automatic route is assumed to exert a fast and transient influence (Ellinghaus et al., 2018, 2024), rising quickly after stimulus onset and then being actively inhibited (Burle et al., 2016; Mittelstadt et al., 2023b; Ridderinkhof, 2002a, 2002b), or passively dissipating after reaching a peak (Hommel, 1993; Ulrich et al., 2015), or both (White et al., 2018).

In our study, masking directional information with overlapping lines may have modulated the onset and strength of automatic activation, enhancing an early spatial influence and increasing the demand on inhibitory control, ultimately shaping response

selection. Two mechanisms described in masked priming research may offer useful insights for interpreting this pattern: first, that perceptual input can influence motor-level processes involved in response selection by modulating the strength of motor activation (Eimer & Schlaghecken, 2002; Ocampo & Finkbeiner, 2013; Schlaghecken et al., 2008); and second, that the mask itself can act as an active component that can both engage inhibitory mechanisms (Jaśkowski & Przekoracka-Krawczyk, 2005; Lleras & Enns, 2004; Schmidt et al., 2022) and interact with directional processes, particularly when it contains task-relevant features resembling the masked stimuli (Verleger et al., 2004). This perspective may help explain why our masking manipulation produced stronger RCEs than those observed in studies using mosaic backgrounds, which lack arrow-like structure (Tanaka et al., 2025b).

Although our manipulation did not involve a masked prime in the traditional sense, the simultaneous presentation of mask and target may have elicited a similar dynamic, though based on simultaneous rather than sequential processing, linking early response activation and inhibition. Specifically, our design likely triggered the parallel processing of three types of information: spatial location (as in any location-based task), mask-related features (which, as noted above, can influence response and inhibition), and target-related directional information, which participants were required to process to perform the task.

The first of these, spatial location, has long been recognized as a well-established source of conflict arising from automatic response activation in spatial interference tasks such as Simon and spatial Stroop (Lu & Proctor, 1995; Ridderinkhof, 2002a, 2002b; Viviani et al., 2024). Typically, spatial interference is thought to emerge at the response selection stage (Lu & Proctor, 1995; Rubichi & Pellicano, 2004; Scerrati et al., 2017), reflecting the dimensional overlap between stimulus and response (S-R) features inherent to the stimulus and task design (Kornblum, 1992; Viviani et al., 2024). However, much like findings from masked priming studies, several authors have also proposed a close link between spatial processing and motor mechanisms (Burle et al., 2016; Miller & Roüast, 2016; Scorolli et al., 2015; Treccani et al., 2018), suggesting that spatial location information may compete with directional information not only during response

selection but also at the motor execution level (Mittelstädt et al., 2023b; Servant et al., 2016; Stürmer et al., 2002).

This dynamic is often described in terms of automatic response capture, where task-irrelevant features involuntarily trigger a response based on stimulus location (Burle et al., 2016; Salzer et al., 2019; van Campen et al., 2014, 2018; van Maanen et al., 2018). For example, a rightward stimulus may automatically activate both the selection of a rightward response and the associated right-hand motor activation, even when the correct response is on the left. In our study, such response capture may have been modulated not only by spatial location but also by features embedded in the mask, thereby increasing early response activation and the need for adequate inhibitory control.

CAF analyses have provided a useful behavioral tool for exploring these dynamics. In location-based tasks, incongruent trials typically produce a higher proportion of errors among the fastest responses, with accuracy converging across conditions in later bins (Torres-Quesada et al., 2022; Ulrich et al., 2015). This pattern is thought to reflect the initial influence of irrelevant spatial information, before inhibition takes effect (Salzer et al., 2019; van Campen et al., 2014, 2018; van Maanen et al., 2018) and/or before the spatial code passively decays. This would explain the standard CAF observed with the level-1 arrows.

However, complex stimuli—such as faces, cropped eyes, and the level-2 and level-3 arrows used here—show notable deviations from this typical pattern. In Ponce et al. (2025a), it was emphasized that such stimuli may convey additional information beyond spatial location, processed within the automatic route. While initially, this additional information was attributed to socially specific features, the present findings suggest that a similar effect may arise from more general, mask-related dynamics. In the case of social stimuli, this may reflect shared visual properties, such as overlapping oval contours (e.g., pupils, eyes, or facial outlines), which could function as task-relevant mask elements embedded within the visual input, similar to the overlapping oblique lines used here. Although further research is needed to clarify how visual similarity and mask geometry influence interference in the spatial Stroop task, we suspect that these masking effects may have modulated early response capture, leading to reduced accuracy in both

congruency conditions, with congruent trials showing even higher error rates than incongruent ones, at specific points in the distribution.

Crucially, this deviation may not reflect enhanced response capture alone but could also indicate additional conflict arising at the level of stimulus identification. The spatial Stroop task is also thought to generate such conflict through S-S overlap (Type-8 ensemble; Kornblum, 1992; Viviani et al., 2024), which may facilitate early processing of mask-related elements. Supporting this view, research on Stroop-like paradigms has shown distinct patterns for S-R and S-S types of conflict (Li et al., 2014; Luo & Proctor, 2017; Scerrati et al., 2017; Torres-Quesada et al., 2022), suggesting that different congruency effects may emerge depending on the source of conflict. Additionally, when the mask contains arrow-like features, it may elicit a form of directionally primed response, similar to those proposed in mask-induced priming accounts (Verleger et al., 2004; Lleras & Enns, 2004), within the automatic route processing stream. This may disrupt the processing of the target's direction and increase congruent-trial errors in the fastest responses, consistent with evidence that automatic activation can briefly spill over into the decision process overseen by the controlled route (Servant et al., 2016; Ülrich et al., 2015).

At a subsequent stage, following the logic of the dual-route framework, automatic activation is held in check by an inhibitory mechanism that receives input from both the automatic and controlled routes (De Jong et al., 1994; Ridderinkhof, 2002a, 2002b; van Campen et al., 2014). This inhibitory mechanism is typically conceptualized as a top-down, feed-forward process (Burle et al., 2004, 2016; Meynier et al., 2009; Ridderinkhof, 2002a, 2002b), and converging evidence describes it as an active process that may complement, rather than rely solely on, the passive dissipation of spatial codes (Burle et al., 2016; Mittelstädt et al., 2023a). Although models vary in how and when the automatic and controlled routes interact, with each other and with inhibition (cf. De Jong et al., 1994; Lu & Proctor, 1995; Kornblum, 1992; Schwarz & Miller, 2012; Ulrich et al., 2015; White et al., 2012), they generally agree that the system must dynamically adapt to context and task demands (Burle et al., 2016; Ellinghaus, et al., 2024; Torres-Quesada et al., 2022; Ulrich et al., 2015).

From this perspective, variations in automatic activation, such as earlier onset or increased strength, should be matched by corresponding adjustments in inhibition. If activation rises sooner or more strongly, as our findings suggest, inhibition must also be initiated earlier and build more rapidly to preserve performance. Indeed, controlled inhibition has been described as a flexible mechanism, adaptable in strength, onset, and buildup rate (Ridderinkhof et al., 2002a, 2002b), and capable of online, reactive adjustment during execution (Burle et al., 2016; Scorolli et al., 2015). These properties offer a plausible account of our results and have previously been associated with RCE patterns observed for social targets (Tanaka et al., 2024, 2025a).

In our study, masked arrows may have amplified early response capture while simultaneously triggering earlier and stronger inhibition, an interpretation supported by the delta plot findings, which showed spatial interference to be markedly reduced among the fastest responses, with the RCE emerging more clearly in the middle range. As noted in the introduction, delta functions represent the time course of congruency effects (De Jong et al., 1994; Pratte et al., 2010). Thus, this early reduction suggests that spatial interference was initially very low, potentially due to the early increase in inhibition, rather than a background segregation mechanism (Tanaka et al., 2024), contrasting with the typical patterns observed for unmasked arrows (Castel et al., 2007; Ponce et al., 2025b; Tanaka et al., 2025a), arrows embedded in complex backgrounds (Tanaka et al., 2025a), and, more broadly, in location-based tasks involving simpler stimuli (Luo & Proctor, 2019; Mittelstädt & Miller, 2020).

This initial suppression may have created conditions for an interaction between additional automatic information, delayed processing of directional relevant information due to the masking effect, and inhibitory mechanisms, ultimately facilitating the RCE. As proposed in prior work (Ponce et al., 2025b), following the second stage of the dual-stage hypothesis (Tanaka et al., 2024, 2025b), one possible scenario is that on incongruent trials, the incorrect response (based on spatial information) is inhibited very early, as reflected in the delta function, so that when the relevant directional code becomes available, the correct response can proceed quickly and accurately as the only remaining, uninhibited option. In contrast, on congruent trials, the inhibitory mechanism suppresses the correct response initially activated by spatial information. Once the relevant directional code is

processed, the system must first release this inhibition before executing the response, resulting in slower RTs and, if not resolved in time, increased early errors, consistent with our CAF findings.

A similar mechanism may underlie gaze-related RCEs. Like masked arrows, gaze can function as a perceptually complex stimulus from which directional information must be extracted amid competing features (Román-Caballero et al., 2021a, 2021b; Tanaka et al., 2024). This complexity may delay access to the relevant signal and recruit inhibition to filter out irrelevant information, effectively making gaze operate as if it were a masked stimulus. Further supporting this view, reducing the complexity of eye stimuli (e.g., using clearly visible schematic eyes) to facilitate access to relevant information results in the SCE (Chen et al., 2022).

Although faces are generally thought to be processed holistically (Hadders-Algra, 2022; Rossion, 2009; Tanaka & Gordon, 2011), with the eyes serving as an anchor point (Itier et al., 2007; Itier & Preston, 2018; Nemrodov et al., 2014), explicit task instructions to attend to gaze direction may disrupt this holistic processing. If this is the case, the face would be treated part by part, with irrelevant features acting like a mask and engaging inhibitory mechanisms to facilitate extraction of gaze direction. This account is consistent with the RCE observed for inverted faces (Marotta & Lupiáñez, 2018; Tanaka et al., 2023), where holistic processing is impaired and feature-based processing predominates (Rossion, 2009; Tanaka & Farah, 1993; Tanaka & Gordon, 2011). It also might underlie the findings of Narganes-Pineda et al. (2022), who observed the RCE only when participants were explicitly instructed to process gaze direction.

At the same time, we cannot exclude the possibility that gaze engages additional mechanisms tied to its social nature (Hemmerich et al., 2022; Marotta et al., 2019), as suggested by further distinctions observed in distributional analyses (Ponce et al., 2025b; Tanaka et al., 2025a). In addition, prior work has demonstrated that the RCE can be modulated by facial emotion (Jones, 2015; Marotta et al., 2022; Torres-Marín et al., 2017), stimulus familiarity (Ishikawa et al., 2024), and individual social anxiety (Ishikawa et al., 2021). Thus, the RCE for gaze may reflect a combination of general inhibitory dynamics linked to perceptual complexity and uniquely social processes.

Critically, this mechanism does not require additional stages beyond those described in the dual-route framework, and a top-down inhibitory mechanism. Rather, it suggests that the RCE may result from adaptive modulations of core parameters within the same architecture, shaped by specific stimulus properties and task demands. Nonetheless, this interpretation does not exclude alternative explanations of the RCE, which future research should continue to examine.

For instance, some findings suggest that target onset may automatically engage inhibitory motor-related processes (Treccani et al., 2018), paralleling the dynamics suggested in some masked priming accounts (e.g., *self-inhibition hypothesis;* Schlaghecken et al., 2008). In this view, bottom-up mechanisms contribute an additional layer of control, whereby activating one response automatically inhibits its alternative, and vice versa. This has been used to explain the negative compatibility effect (Eimer & Schlaghecken, 2002; Schlaghecken et al., 2008), and could provide a comparable account for the RCE, where inhibition of one response alternative leads to disinhibition of the opposite response.

Additionally, as discussed earlier, participants appeared to adopt a global strategy based on target predictability (see **Experiment 2**), which modulated the interference effect to some extent. In this context, cognitive control strategies are often conceptualized as either sustained (global) or reactive (trial-by-trial) responses to conflict (Torres-Quesada et al., 2022). However, the RCE persisted for the most complex targets regardless of presentation format, and the direction of Stroop interference remained stable across blocks (see **Supplemental Material**). These patterns suggest that, despite global adjustments, the RCE may be driven by trial-level mechanisms. This view is supported by the dual-route framework and accumulation models, which emphasize single-trial adjustments in conflict resolution via dynamic tuning of key parameters (Lee & Sewell, 2023; Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015).

Overall, these findings suggest that the emergence and magnitude of the RCE are shaped by perceptual complexity, control mechanisms and task-related dynamics. By examining accuracy and interference across the RT distribution, we revealed patterns that would be missed by mean-based analyses. This approach supports prior recommendations to use distributional methods to capture the temporal profile of conflict

(Balota & Yap, 2011; Ellinghaus et al., 2024; Mittelstädt & Miller, 2020; Pratte et al., 2010). Moreover, our results align with those of Román-Caballero et al. (2021a, 2021b), who found that reductions in the SCE often co-occur with increases in the RCE, suggesting a functional link between them. Although a full examination of this relationship was not the focus of the present study, our findings underscore the need for future research to clarify when the RCE is enhanced or suppressed.

Conclusions

This study reveals that the RCE, typically observed with social targets, can also be elicited with non-social stimuli when directional information is masked by overlapping features. This supports the view that the RCE is not exclusive to social processing but can arise from general constraints on information accessibility and cognitive control. By integrating insights from the dual-route framework and masked priming literature, we suggest that early response activation, inhibitory mechanisms, and visual complexity interact to shape spatial interference patterns. Distributional analyses revealed that the RCE unfolds over time, with minimal interference in early responses and stronger reversal at mid-range latencies. Importantly, the comparison between masked arrows and gaze highlights a potential bridge between social and non-social accounts: whereas arrows require an explicit masking manipulation, gaze may spontaneously engage inhibitory mechanisms due to its perceptually complex configuration. Taken together, these results suggest that the RCE reflects adaptive control processes that flexibly adjust to perceptual complexity and task context. Further research is needed to clarify how these factors interact to enhance or suppress this effect.

Supporting Information

The Supplemental Materials for Study 4 can be found in **Appendix C**.

CHAPTER 4. GENERAL DISCUSSION

Social attention encompasses the processes that allow humans to detect and respond to socially relevant signals such as gaze, facial expressions, and body posture. These cues guide attention effortlessly, either by orienting focus toward relevant information or by conveying communicative content essential for social interactions. Among them, gaze has been one of the most extensively studied, as it combines a strong orienting function with communicative value, linking basic attentional shifts to higher-order processes such as joint and shared attention mediated by attentional control mechanisms (**Section 1.3**).

Research using the gaze-cueing paradigm provided early evidence of these dynamics. Classic findings showed that gaze automatically orients attention even when non-predictive of target location (Friesen & Kingstone, 1998). Crucially, however, other orienting cues such as arrows produce very similar cueing effects, and a meta-analysis confirmed that the two stimuli elicit broadly comparable orienting behaviors across a wide range of conditions (Chacón-Candia, Román-Caballero, et al., 2023). From this perspective, gaze cueing appears largely supported by domain-general attentional mechanisms.

At the same time, later studies have shown that qualitative differences can emerge when the gaze-cueing paradigm is combined with additional manipulations, for example, in object-based attention, working memory, or affective evaluation (**Section 1.3.2.**). These findings suggest that gaze, under specific circumstances, may engage processes beyond domain-general mechanisms. However, they also raised concerns that the gaze-cueing paradigm might not be sensitive enough to fully capture such dissociations (Chacón-Candia, Román-Caballero, et al., 2023).

A turning point came with the discovery by Cañadas and Lupiáñez (2012), who reported the reversed congruency effect (RCE), when gaze stimuli were used as directional targets in a spatial Stroop task (**Section 1.4.1.**). In this task, irrelevant spatial position competes with directional meaning, providing a complementary test of whether gaze might elicit a distinctive pattern. The RCE is characterized by its counterintuitive result: participants responded faster to incongruent than to congruent trials. This finding was striking not only for its novelty but also for its conceptual implications. It appeared capable of overturning the well-established standard congruency effect (SCE),

consistently observed in location-based tasks, where irrelevant spatial information of the stimulus (i.e., its location of appearance) serves as a robust source of conflict.

The effect was later replicated and linked to social and communicative mechanisms (Jones, 2015; Torres-Marín et al., 2017). For this reason, it soon became part of the broader debate about the "special" nature of gaze-related attentional effects (Marotta et al., 2018), offering a complementary perspective in which differences between gaze and non-social stimuli became more apparent (e.g., Bonventre & Marotta, 2023; Ishikawa et al., 2021; Marotta et al., 2019).

In line with this view, several accounts emphasized the possibility that the RCE reflects a specifically social mechanism, tied to the communicative significance of gaze (Edwards et al., 2020; Hemmerich et al., 2022; Marotta et al., 2018). Such interpretations reinforced the idea that gaze may engage processes distinct from those underlying non-social cues like arrows

However, evidence suggesting a reciprocal relationship between the RCE and the SCE, encouraged researchers to move toward a more integrated account (Marotta et al., 2019; Román-Caballero et al., 2021a, 2021b). Hemmerich et al. (2022) formalized this view by explicitly outlining an account based on the interplay of shared and unique mechanisms, in which a gaze-related component overrides and reverses the typical pattern of spatial interferences.

While this framework emphasized social influences as the primary driver of the RCE, subsequent research has produced multiple findings suggesting that the effect cannot be fully explained by a single source. Instead, it might reflect the interplay of multiple factors, including perceptual discriminability, temporal dynamics, and the social significance of stimuli (**Section 1.4.3.**). In this thesis, the RCE is therefore conceived as the outcome of interacting mechanisms rather than as a strict opposition between social and non-social components, a perspective that guided the examination of its characteristics and underlying dynamics.

Building on these, the present work sought to contribute to the development of the integrative framework by investigating how social, perceptual, and task-related mechanisms interact in shaping the reversal, and by assessing the extent to which social and non-social factors played a role in its emergence. To address these issues in a

systematic way, the research was organized around two main goals. The first was to begin profiling the RCE across gaze and arrow stimuli using a distributional approach within the dual-route framework, thereby capturing the temporal dynamics of interference. The second was to test whether non-social stimuli could elicit reversal-like patterns when their perceptual properties were manipulated to mimic features of gaze.

The purpose of this chapter is to integrate these contributions, clarify their implications, and identify directions for future research. **Section 4.1** provides a summary of the main contributions of the thesis, showing how each study builds toward understanding the RCE as a multi-dimensional phenomenon. **Section 4.2** discusses a possible mechanism underlying its dynamic. **Section 4.3** outlines avenues for future research, both conceptual and methodological, that could extend the present findings. Finally, **Section 4.4** presents concluding remarks that synthesize the overall message of the thesis and its relevance for the study of attentional orienting and control mechanisms.

4.1. Summary of Contributions

4.1.1. Empirical Contributions

Building on the reports presented in **Chapter III**, the following section reviews the empirical contributions of the four studies. Each study addressed specific aspects of the RCE in line with the thesis aims.

Study 1 examined the temporal dynamics underlying the dissociation between social and non-social targets by analyzing how accuracy changes as a function of response speed. To this end, CAFs were applied to trace accuracy across the RT distribution, and model-based analyses using linear mixed models (LMMs) were employed to test specific contrasts. Data were re-analyzed from 11 studies (16 experiments, 705 participants).

The study was designed with three complementary goals. First, it aimed to determine whether CAFs could reveal early-stage differences between social and non-social targets, thereby extending beyond the RT-based approaches typically used in this literature. Second, it sought to disentangle the contribution of broader facial context by contrasting full faces with isolated eyes, testing whether the presence of additional facial information shifted the point at which interference patterns emerged. Third, it explored whether affective cues embedded in facial expressions further modulate the reversal, adding either a communicative or emotional dimension, or distinctive morphology to the observed dynamics. To this end, three models were built: model MA, comparing social versus non-social targets; model MB, distinguishing between faces and isolated eyes and comparing them with arrows; and model MC, comparing faces with different emotional expressions.

Results of model MA confirmed well-known patterns for non-social targets: accuracy was stable for congruent trials but dropped sharply for incongruent ones in the fastest bin, improving at slower latencies. This reflects automatic capture, where responses are selected based on irrelevant spatial information rather than target direction before inhibition can act or location codes decay (see **Section 1.4.4.**). Social targets, in contrast, showed a different profile: both congruent and incongruent trials were less accurate in the fastest bin, and crucially, congruent trials produce lower accuracy than incongruent ones at early latencies, reversing the typical pattern.

Model MB refined this dissociation by showing that the reversal emerged earlier and more robustly for faces than for isolated eyes. For faces, congruent trials were significantly less accurate than incongruent ones in the first two bins, whereas for cropped eyes this effect was weaker and limited to the second bin. Arrows, by contrast, followed the classic SCE profile.

Model MC further examined the role of facial expressions. When all expressions were considered together, congruent trials were consistently less accurate than incongruent ones, and this RCE extended from the first to the third bin. However, no triple interaction between expression, congruency, and bin was observed, indicating that emotional expressions did not systematically modulate the congruency effect at the distributional level. Instead, emotions influenced overall accuracy patterns: anger and happiness expressions particularly exacerbated accuracy costs in congruent trials, whereas fearful faces were associated with relatively higher accuracy.

Study 2 complemented the CAF analyses by using delta functions to trace how congruency effects unfolded across the RT distribution. A similar approach as in Study 1 was employed, re-analyzing the same datasets (11 studies, 16 experiments, 705 participants) and applying LMMs for specific contrasts.

The study pursued three goals. First, it aimed to describe how congruency effects unfolded across quantiles for social versus non-social targets. Second, it examined when reversal-like patterns appeared and how their slope or curvature evolved across the distribution. Third, it compared faces with isolated eyes to test whether broader facial context altered the timing or magnitude of reversal effects. To this end, three complementary models were built: an RT model based on CDFs, a delta model assessing interference changes across quantiles, and a Trend model capturing the overall trajectory of the delta functions.

The RT model revealed the typical differences in overall response times: arrows were faster than social stimuli. In terms of congruency, arrows showed the expected SCE, whereas both faces and eyes showed an RCE. Interestingly, no differences emerged between the two social targets.

The delta model showed that arrows maintained a stable SCE across the distribution, whereas both faces and eyes produced negative delta values, indicating an

RCE. No significant overall difference was observed between faces and isolated eyes. At the distributional level, the RCE emerged from the second quantile onward and became more pronounced at middle-range latencies, while the first quantile did not differ from zero. At the slowest responses, faces showed a stronger reversal than eyes. Arrows, in contrast, maintained a positive SCE at every quantile. Additional quartile and decile models replicated this pattern and ruled out trimming artifacts.

The Trend model showed that faces displayed the steepest negative slope, followed by eyes, both differing significantly from arrows across all models. Arrows showed no reliable linear or quadratic trend, as their components seemed to depend on the number of quantiles and whether trimming was applied. By contrast, faces and eyes consistently combined a negative linear trend with a positive quadratic component, producing a curved "U-shaped" profile: the RCE strengthened progressively with slower responses but tended to level off at the very slowest latencies. This pattern confirms that the RCE for social stimuli followed a qualitatively different trajectory from the stable interference profile observed with arrows.

Study 3 investigated whether manipulating the perceptual contrast of arrows could approximate gaze-like reversal patterns in the spatial Stroop task, particularly the reversed CAFs observed in **Study 1.** Two arrow types were designed: a *gaze-similar* version (dark head on light body, resembling iris–sclera contrast, where the more salient part of the arrow is opposite to the target head) and a *gaze-opposite* version (light head on dark body, reversing this relation). Data were collected across two preregistered experiments.

The study was guided by three objectives. First, it tested whether the contrast polarity of arrows, specifically gaze-similar targets, could reverse the SCE, thereby mimicking gaze-like dynamics. Second, it examined whether embedding arrows in visually complex backgrounds would further weaken spatial interference and potentially expose reversal tendencies due to the contrasts of the target types. Third, it aimed to trace how these effects unfolded over time using distributional tools (CAFs and delta plots), allowing a detailed comparison between gaze-similar and gaze-opposite arrows across the RT distribution.

Across both experiments, no RCE was observed at either the mean-level or the distributional level. Congruency effects remained positive in all conditions, although their size varied with arrow contrast and background complexity. Thus, contrast manipulations altered the magnitude of interference but were insufficient to induce a full reversal of the congruency effect observed with arrows.

In Experiment 1 both target types elicited an SCE, with faster and more accurate responses on congruent than incongruent trials. The effect was larger for gaze-opposite arrows, driven by faster responses on their congruent trials, which increased the difference between congruency levels. CAFs confirmed the typical non-social pattern for both target types, while delta plots showed robust positive congruency effects across all quantiles, which decreased slightly as response slowed.

Experiment 2 was designed to replicate these results and to test the effect of adding a visually complex background, creating two experimental blocks: one with and one without background. Overall, analysis showed similar patterns to Experiment 1 when the background was absent. At the same time, the complex background produced slower and less accurate responses. Congruency effects were robust in the background-absent condition, as in Experiment 1, but were reduced to a null effect when the background was present. In addition, the conflict effect was larger for gaze-opposite arrows, again driven by faster responses on congruent trials.

CAF analyses showed the typical non-social profile in the background-absent condition, replicating Experiment 1. In the background-present condition, accuracy reductions were observed for both congruent and incongruent trials within the fastest responses, but no reversal emerged. Delta plots revealed that congruency effects were larger without backgrounds, eliciting a consistent SCE across the distribution. When backgrounds were added, the effects were strongly reduced, remaining positive in the first quantile for both target types and in the fifth quantile for gaze-opposite arrows, but null in the other quantiles. No RCE emerged for either target type at any point in the distribution.

Study 4 extended this line of research by introducing a masking manipulation designed to hinder access to directional information in arrow targets, analogous to how facial or eye-region context is thought to reduce directional clarity for gaze stimuli. Two

preregistered experiments were conducted using visually masked arrows with oblique lines at three levels of difficulty.

The study was guided by three main goals. First, to test whether masked arrows could generate an RCE. Second, to examine whether the reversal reflected a general adjustment of control mechanisms or the specific perceptual complexity of the stimuli, addressed through a block structure manipulation with two different groups: a within-block group, where target types were intermixed, and a between-block group, where target types were presented in separate blocks, altering target predictability. Third, to compare masked arrows with gaze across the RT distribution, evaluating whether perceptual difficulty and the potential social meaning of gaze converge or diverge in producing reversal dynamics.

Across both experiments, masked arrows effectively produced reversal dynamics. In addition, comparisons with gaze indicated substantial overlap at both the mean and the distributional levels, though some differences remained.

Experiment 1 showed a clear dissociation: minimally masked arrows (level 1) elicited the standard SCE, while more heavily masked arrows (levels 2 and 3) produced significant RCEs. Accuracy declined as masking increased, though only level-1 arrows showed a significant congruency effect, with congruent trials more accurate than incongruent ones. CAFs confirmed the typical non-social profile for level-1 stimuli, whereas masked arrows showed reduced accuracy for both congruency levels in the fastest responses, without significant reversed patterns. Delta plots indicated a stable SCE for level-1 arrows and reversals for levels 2 and 3 since intermediate quantiles.

Experiment 2 replicated these findings while adding gaze stimuli and the between groups manipulation of the target type (within-block vs. between-blocks). At the mean RT level, level-1 arrows again produced an SCE, whereas levels 2 and 3, as well as gaze, produced robust RCEs of comparable size. Accuracy patterns showed a reversal for heavily masked arrows (level 3), and an SCE for level-1 arrows. The block manipulation revealed slower responses in the within-block group compared to the between-block group, and larger reversals under within-block presentation.

CAF analysis was notably modulated by group. Level-1 arrows displayed the typical non-social pattern in both conditions, though the effect was larger in the between-

block group. Level-2 and level-3 arrows replicated the Experiment 1 pattern of reduced accuracy for both trial types in the fastest responses, but also produced reversals at bin 2 (with level-2 arrows in the within-block group; and with level-3 arrows in both groups). Gaze showed a hybrid profile, with an SCE at the first bin under between-block presentation, and a reversal in the third bin under within-block presentation.

Delta plots indicated a stable SCE for level-1 arrows, and consistent RCEs for levels 2 and 3, except for the first quantile for level 2, which showed a null effect. Gaze again showed a mixed pattern, with an SCE at the fastest responses that transitioned into an RCE at slower quantiles. Planned contrasts revealed that the SCE for level-1 arrows was most stable in the between-block group, whereas gaze showed an SCE at the fastest quantiles only in the between-block group and reversals from the second quantile onward in the within-block group. No group differences were observed with levels 2 and 3.

In addition to the four main studies, the pre-cueing study examined how attentional orienting and alerting modulate spatial interference using gaze and arrow targets (see **Appendix D**). Two preregistered experiments were conducted to test whether pre-cueing (via peripheral cues) and alerting (via warning tones) influence SCE and RCE patterns in opposite ways. Although the expected complementary modulation between both conflict types was not consistently observed, both experiments showed reliable main effects of validity and alerting: valid and tone trials elicited faster responses than invalid and no-tone trials, indicating that the manipulations produced the expected effects overall (Funes et al., 2007; Funes & Lupiáñez, 2003).

In addition, a robust SCE with arrows was observed across all conditions, confirming its stability across manipulations. In contrast, the gaze-related effect varied without a consistent pattern, suggesting a more complex system underlying its processing dynamics that warrants further examination. These findings suggest that the interaction between orienting and alerting does not necessarily yield additive changes in the SCE and RCE, highlighting that the dynamics between these two conflict types may depend on distinct and context-sensitive mechanisms.

Together, these empirical findings provide a comprehensive profile of the RCE across social and non-social targets. The results demonstrate that the RCE is not restricted

to social stimuli and is further shaped by context and task demands, laying the groundwork for broader theoretical and methodological implications. The next section turns to these contributions, situating the present findings within the debate on the nature of the RCE and its underlying mechanisms.

4.1.2. Theoretical Contributions

A central theoretical contribution of this thesis is to advance the debate over whether the RCE reflects a domain-general mechanism, or whether it is inherently tied to gaze-specific components. The findings of **Study 4** provided compelling evidence that the reversal can be elicited by non-social targets when perceptual constraints are imposed. This suggests that hindering access to task-relevant information through visual masking can generate the dynamics that allow an RCE to emerge.

Previous research had already hinted at this possibility (Y. Tanaka et al., 2024) and attempted to create the conditions necessary for a reversal. For example, arrows embedded in complex backgrounds showed attenuated interference effects (Román-Caballero et al., 2021b, 2021a; Y. Tanaka et al., 2024, 2025) and, in rare cases, even reversal-like outcomes (Román-Caballero et al., 2021a, experiment 1) or local reversals at certain portions of the response distribution (Y. Tanaka et al., 2025, supplemental material). However, these effects were typically weaker than those observed with gaze, limited to specific quantiles, or unstable across replications (cf. Román-Caballero et al., 2021a, 2021b; Y. Tanaka et al., 2024). As a result, they are more appropriately interpreted as partial reductions of interference rather than robust RCEs.

One reason for these limitations may be that the RCE requires more than an increase in visual complexity. Although background manipulations do raise task demands, they may not provide the kind of additional input capable of altering response dynamics in ways that produce a reversal. Instead, visually complex backgrounds likely acted as generic noise. This could explain why face-like backgrounds (Román-Caballero et al., 2021a, experiment 2), mosaic backgrounds (**Study 3**; Y. Tanaka et al., 2024), and pixelated backgrounds (Román-Caballero et al., 2021b) did not elicit gaze-like patterns.

By contrast, the oblique-line masks used in **Study 4** appear to have introduced a critical component, fundamentally altering how conflict unfolded in the spatial Stroop task. Insights from the literature on masked priming are particularly relevant here, given

the observation of a functionally similar phenomenon to the RCE: the negative compatibility effect (NCE).

The NCE shows that when a prime is masked, the usual facilitation for congruent targets can reverse, leading to slower or less accurate responses (Eimer & Schlaghecken, 2002). To account for this, researchers have proposed different explanations, ranging from selective inhibition of the primed response (*self-inhibition hypothesis;* Schlaghecken & Eimer, 2002), to the idea that the mask itself provides response-relevant features that bias selection (*object-updating account;* Lleras & Enns, 2004; and *active-mask hypothesis*; Verleger et al., 2004), and to the proposal that the mask acts as a stop signal that suppresses premature response activation (*mask-triggered inhibition hypothesis;* Jaśkowski & Przekoracka-Krawczyk, 2005). Despite their differences, these accounts converge on a key idea: masks actively shape performance, either by adding extra information to the processing stream and/or by altering inhibitory mechanisms in ways that can reverse the usual prime-target pattern.

The manipulation in **Study 4** may have played a similar role. The oblique-line structure could have introduced additional information capable of interacting with target direction and/or eliciting inhibitory mechanisms akin to those described in the NCE literature (outlined below). Assuming the first possibility, the mask would share certain perceptual or directional features with the target, allowing the two to be partially integrated into the same perceptual object while still retaining enough independence for the mask to generate its own signals. Such partial independence might explain why complex backgrounds failed to produce an RCE: their elements lacked the degree of separation necessary for the stimuli to exert an independent influence. Thus, the masking manipulation not only increased perceptual load but also added active signals into the processing stream, creating the appropriate conditions for the reversal to emerge.

The close correspondence between the RCE elicited by gaze and by masked arrows in **Study 4**, together with their highly similar distributional profiles with the other studies, suggests that the underlying mechanisms may operate in comparable ways. From this perspective, the masking manipulation in arrows could serve as an experimental analogue of the natural perceptual configuration found in gaze stimuli. Both configurations may introduce overlapping but partially independent visual

components capable of interacting with directional information and modulating conflict resolution. In full-face gaze stimuli, for instance, overlapping features such as iris, sclera, and facial contours (e.g., nose, mouth, etc.) may naturally provide the additional inputs which, rather than being ignored, influence final outcomes.

This interpretation aligns with the suggestion that the spatial Stroop task might alter holistic face processing (Y. Tanaka et al., 2023). As mentioned earlier, faces are typically processed through holistic and/or configural modes (**Section1.3.1.**). However, explicitly instructing participants to focus on gaze direction might disrupt this holistic mode, potentially encouraging a more piecemeal analysis of facial parts. Under such conditions, task-irrelevant facial elements could act as perceptual masks, retaining enough independence to elicit their own processing. Supporting this view, inverted faces, known to impair typical face processing (Rossion, 2009; J. W. Tanaka & Farah, 1993), have been shown to produce robust RCEs comparable to those observed with upright faces (Marotta & Lupiáñez, 2018; Y. Tanaka et al., 2023). Similarly, reversals emerge only when participants are explicitly asked to process gaze direction (Narganes-Pineda, Chica, et al., 2023).

These observations also offer a useful framework for interpreting developmental findings. If the interaction between masking elements and the target depends on how holistic and configural information are processed, differences in the maturity of these mechanisms could explain the age-related patterns observed in Aranda-Martín et al. (2022). In the four-year-old group, an SCE with complex faces was observed. One possible explanation is that the task only partially disrupts holistic face processing. At this age, the configural mode may not yet be fully developed, whereas holistic processing already is (Mondloch et al., 2002; Taylor et al., 2004). Consequently, faces may still be perceived as undifferentiated wholes, preventing the segregation of parts that would otherwise act as a mask.

By contrast, in children aged five, six, and ten years, the configural mode might be active, although not yet adult-like. In this case, the disruption induced by the spatial Stroop task could cause surrounding facial features to be processed more like neutral visual noise (similar to complex backgrounds) rather than as interfering components of a

compound stimulus. This may explain the absence of conflict effects in children of those ages.

From this perspective, the contribution of surrounding elements may depend on the engagement of holistic and configural modes, whose relative influence, depending on their level of maturity, could underlie the patterns observed in children. This interpretation aligns with prior literature showing that holistic processing appears early in life, whereas configural processing continues to refine over a longer period (Miki et al., 2015; Mondloch et al., 2002; Taylor et al., 2004). Moreover, general observations from behavioral and electrophysiological studies reveal distinctive patters compared with adults (de Haan et al., 2003; Miki et al., 2015; Pellicano & Rhodes, 2003; Taylor et al., 2001), indicating that face-processing performance improves with age, not only for upright faces but also for inverted ones (Picozzi et al., 2009; Sun et al., 2020; Taylor et al., 2004).

However, these interpretation should be taken with caution. On one hand, although evidence converges on the early emergence of holistic processing (Farroni et al., 2000; Kavšek et al., 2022; Kuo & Chien, 2021; Nakabayashi & Liu, 2014), the maturation of configural processing remains a matter of debate (cf., McKone & Boyer, 2006; Mondloch et al., 2002; Petrakova et al., 2018; Taylor et al., 2004). On the other hand, the differences observed between children and adults may not strictly reflect the development of face-specific mechanisms but rather broader maturational changes in perceptual and attentional systems, as suggested by other researchers (e.g., Gerlach et al., 2023; Pellicano et al., 2006; Petrakova et al., 2018). Additionally, research on object recognition involving configural and feature-based processing suggests improvements continuing into adolescence (Davidoff & Roberson, 2002; Jüttner et al., 2013). Thus, the dissociation observed in Aranda-Martín et al. (2022) might reflect a more general mechanism. This account is therefore worth examining further. Future research should compare faces and masked arrows in children to determine whether similar developmental profiles emerge.

Taken together, these findings suggest that the RCE is neither a social effect per se nor the outcome of a single mechanism. Rather, it reflects a broader principle: when additional visual elements interact with task-relevant processing, whether in social or non-social contexts, they reshape spatial interference and, consequently, response

selection. Reversal effects appear to emerge when holistic processing is disrupted in faces or when additional visual information becomes integrated as part of the task-relevant information in non-social stimuli. In both cases, the surrounding elements may act as non-neutral visual masks, altering directional information and, as discussed later, potentially also influencing control dynamics.

A second theoretical contribution of this thesis is to analyze how different influences converge to shape the RCE and its dynamic. While **Study 4** demonstrated that non-social constraints are sufficient to elicit the reversal, the broader pattern of results across studies indicates that task-related factors, and potentially social factors, can modulate both its emergence and its unfolding dynamics. From this perspective, the effect profile would be best understood as the outcome of interacting influences.

One useful way to frame this interaction is through the continuum of perceptual complexity and social meaning proposed for gaze stimuli (Aranda Martín, 2023). At one extreme, full faces with emotional expressions present high perceptual complexity while amplifying the communicative signal of gaze. At the other extreme, schematic or cartoon eyes present highly accessible directional cues but reduced social features, making their processing more comparable to arrows.

Viewed in this light, the distributional findings gain added significance. If perceptual masking or the communicative value of gaze were the only modulators of the reversal, one would expect faces and isolated eyes to produce distinct outcomes, since faces provide more additional information that could alter response dynamics. Yet the analyses revealed both overlaps and divergences between these social stimuli. On the one hand, CAFs highlighted distinctive patterns in the fastest responses, with faces producing stronger and earlier reversals, particularly when emotional expressions were present (**Study 1**). On the other hand, delta function analyses suggested that both faces and eyes shared a broadly similar trajectory in the development of the reversal, with differences only becoming apparent at the slowest responses (**Study 2**).

Although the stronger CAF effects for emotional faces compared to eyes were initially attributed to their social significance, the observation of reversed CAFs with masked arrows suggests a more general mechanism. Consistent with this view, CAFs observed in masked priming research have also shown marked reductions in congruent

trials, with reversals emerging at certain points of the distribution (e.g., Panis & Schmidt, 2016; Schmidt et al., 2022). Thus, more complex stimuli, such as emotional faces, may alter further the underlying dynamic by adding extra information around the target's direction, thereby amplifying the "masking effect". This interpretation fits naturally with a continuum based on perceptual complexity: both faces and masked arrows add "extra" elements compared to isolated eyes, thereby further modulating conflict and control.

However, the parallel patterns in the delta functions for social stimuli and masked arrows—particularly the tendency to elicit null effects at the first quantile followed by reversals at subsequent quantiles—suggest that neither perceptual complexity nor social meaning can fully explain the phenomenon. This apparent rupture in the continuum points instead to the involvement of additional factors to consider. One plausible possibility is that conflict occurs at multiple processing stages, each reflected differently in the distributional tools.

The Stroop effect itself can be described as a multi-stage, multi-locus phenomenon (Banich, 2019; De Houwer, 2003; Parris et al., 2022b), and this view has been extended to the spatial Stroop effect (Viviani, Visalli, Montefinese, et al., 2024). In particular, the task can elicit both S-S and S-R overlap (**Section 1.2.2.**), making it plausible that the conflict effects observed in the present work may reflect the joint contribution of both.

Indeed, some research supports the additivity of conflict effects arising from S-S and S-R, potentially indicating partial independence (Li et al., 2014; Liu et al., 2010). This is reinforced by evidence from studies comparing the neural correlates of tasks that elicit specifically S-S or S-R conflict (Liu et al., 2004). Moreover, further differences between these two types of conflict have been observed in their distributional profiles, particularly through delta function analyses (C. Luo & Proctor, 2017, 2019; Scerrati et al., 2017; Torres-Quesada et al., 2022).

Although the present data do not allow us to disentangle directly the relative contributions of S-S and S-R conflict dynamics, some of the patterns observed across our studies may provide useful clues for future work. For instance, in visual Simon tasks—where conflict is thought to arise mainly at the S-R locus, also stemming from a spatial location sources as in the spatial Stroop (Kornblum, 1992; Lu & Proctor, 1995; Viviani, Visalli, Montefinese, et al., 2024)—the delta function with non-social stimuli typically

diminishes and can even approach zero at slower latencies (C. Luo & Proctor, 2019; Mittelstädt & Miller, 2020; Zhong et al., 2020). By contrast, both the present analyses (**Study 2** and **3**) and previous work (Castel et al., 2007; Juncos-Rabadán et al., 2008; Y. Tanaka et al., 2025) showed that interference in the spatial Stroop with non-social targets persists across the distribution, with only limited reductions at slower responses.

This persistence may reflect sustained conflict, possibly arising from the combined contribution of different loci. Consistent with this considerations, while some studies have shown the S-R conflict decaying at slower responses, as mentioned above, S-S conflict remains (C. Luo & Proctor, 2017; Scerrati et al., 2017), and sometimes even increases (Torres-Quesada et al., 2022, see the younger adult group). The combination of both may therefore elicit a sustained SCE.

From this perspective, there is no reason to assume that the RCE would not also be shaped, at least to some extent, by this same task-related structure. A key question, however, is whether both loci contribute simultaneously, or whether the weight of conflict resolution shifts toward one locus or the other depending on task conditions.

Relevant evidence comes from the explicit verbal task of Narganes-Pineda, Chica, et al. (2023, Experiment 3A), reanalyzed in **Appendix E** using distributional tools. In this task, participants reported the target's direction verbally while ignoring its spatial location. The results showed that the gaze CAF elicited neither reversals nor reductions in accuracy at the fastest responses of either congruent or incongruent trials. By contrast, the delta functions in the same task did reveal the RCE at specific quantiles of the distribution. This suggests that while the combination of S–S and S–R conflict may sustain interference in motor tasks, the reversal can still emerge when only stimulus-based conflicts are at play.

The absence of CAF reversals can be interpreted as direct consequence of changing response modality. Participants may have adopted a strategy that slowed responses and increased overall accuracy, thereby removing the possibility of capturing the typical CAF pattern, which rely on automatic errors (Burle et al., 2016), for both arrows and gaze targets. Supporting this view, similar outcomes have been reported when responses are given with slower effectors (e.g., foot vs. hand; Mittelstädt & Miller, 2020) or under accuracy-focused instructions (Heuer & Wühr, 2023). The delta results,

however, point to a different interpretation: the RCE may originate earlier, during stimulus-processing stages. Indeed, by removing manual responses, it is assumed to eliminate S-R overlap (Viviani, Visalli, Montefinese, et al., 2024), localizing interference primarily to the stimulus-identification stage (Kornblum, 1994).

These complementary findings highlight that CAFs and delta functions capture different facets of the reversal, and that response modality can act as a modulator of how these distributional profiles unfold. More broadly, these task structure might elicit some modulations, although not impede the RCE to emerge.

Beyond these task-related considerations, an open question that remains is whether social-related components of gaze act as modulators of the reversal. While the present findings suggest they do not need to be the primary drivers, they cannot be entirely discounted, as gaze continues to show distinctive patterns compared to non-social stimuli.

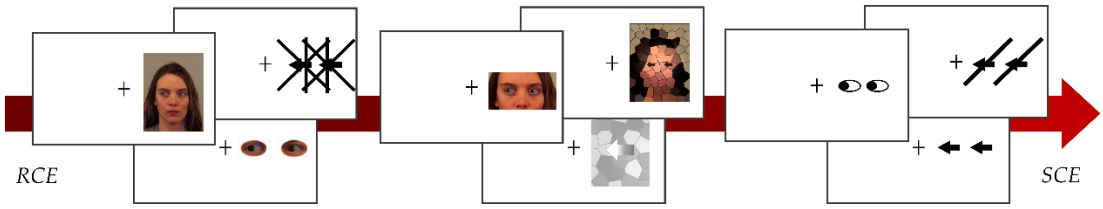
In **Study 1**, faces elicited stronger CAF effects than those observed with masked arrows in **Study 4**. Social stimuli also showed a stable quadratic trend in delta functions, which may distinguish them from masked arrows, though direct comparisons remain open. While eyes and faces followed similar trajectories at faster and middle quantiles, they diverged at the slowest responses, one possibility is that higher-order processes, that could be linked to social meaning, might come into play as they need more time to be executed. In addition, the gaze stimuli in **Study 4** showed a hybrid conflict pattern, differing from both arrows and full faces. This might be due to their cropped presentation, which omitted features such as the mouth and reduced facial complexity. At the same time their design may have made them easier to process than masked arrows, as suggested, in the discussion of the study, and perhaps even easier than isolated eyes.

Taken together, these findings suggest that the continuum proposed for gaze stimuli can be expanded, shifting the emphasis from stimulus properties alone toward the range of outcomes they produce. At one extreme would lie conditions that consistently elicit robust reversals profiles, such as complex stimuli masked by non-neutral features in tasks combining both S–S and S–R overlap. Moving toward the middle, targets embedded in complex backgrounds—or tasks focusing on non-directional features such as color—sometimes produce local or unstable reversals but more reliably

attenuate interference. At the opposite extreme, highly simplified targets such as schematic or cartoon eyes typically yield the classic SCE (**Figure 6**).

Figure 6

Continuum of Spatial Stroop Stimuli and Conflict Outcomes



Note. The continuum illustrates how different spatial Stroop stimuli vary in both their properties and the outcomes they produce. Complex stimuli such as faces or masked arrows tend to elicit reversals, intermediate conditions often attenuate interference, and simplified targets such as schematic eyes or arrows typically yield the SCE.

Finally, a third contribution of our research concerns the broader control mechanisms typically discussed in conflict-task research. As outlined in **Section 1.4.4.**, within the dual-route framework, accounts differ on whether interference resolves primarily through the passive decay of irrelevant codes or the active suppression of competing information.

As mentioned in previous paragraphs, in spatial paradigms, conflict arises from the irrelevant location of the stimulus: even when participants are instructed to ignore it, spatial information is automatically processed and disrupts goal-directed responses (**Section 1.2.2.**). This conflicting information is assumed to produce a transient activation, a brief, pulse-like signal that reaches a peak and then diminishes (Ulrich et al., 2015). Its strength and timing shape the observed conflict effects, either by fading on its own (Hommel, 1993), or by triggering active control mechanisms (Ellinghaus et al., 2024; Mittelstädt et al., 2022; Mittelstädt, Leuthold, et al., 2023; Ridderinkhof, 2002a, 2002b).

To capture these dynamics, distributional tools have provided important insights (Balota & Yap, 2011; De Jong et al., 1994; Mittelstädt & Miller, 2020; Ridderinkhof, 2002a; van Campen et al., 2014). Specifically, the delta function is interpreted as indexing the time course of inhibitory mechanisms, the dissipation of the location code, or the relative speed between relevant and irrelevant information (**Section 1.4.4.**). These interpretations are consistent with the typical negative-going delta plots observed in location-based tasks

(Ambrosi et al., 2019; De Jong et al., 1994; Debey et al., 2015; Ridderinkhof, 2002a), where the fastest responses tend to be most affected by conflicting information (due to the early impact of the irrelevant dimension), whereas slower responses are less affected, as control processes have had time to operate (decay or inhibition).

However, across studies, the delta function analyses with complex stimuli did not show the predicted spatial interference at the fastest quantiles. Instead, interference was markedly reduced. This pattern emerged consistently: with faces, isolated eyes, and masked arrows (**Study 2** and **4**), and with arrows presented against complex backgrounds (**Study 3**). Comparable reductions were also observed with tongue targets (Y. Tanaka et al., 2025, supplemental material).

These observations are difficult to reconcile with a passive decay account, which would predict interference in fast responses until location codes peaked and then gradually faded (Hommel, 1993; Ulrich et al., 2015). An alternative possibility is the rapid engagement of inhibitory mechanisms capable of suppressing conflict earlier (or faster) than typically assumed.

This interpretation aligns with active inhibition models, which describe inhibition as a flexible, adaptive, top-down process (Burle et al., 2016; Ellinghaus et al., 2024; Forstmann et al., 2008; Ridderinkhof, 2002a, 2002b). Such models emphasize that inhibition can vary in onset, strength, and build-up rate, and can adapt to the demands imposed by the perceptual complexity or task context (Ellinghaus et al., 2024; Mittelstädt, Leuthold, et al., 2023; Mittelstädt & Miller, 2020; Proctor et al., 2011).

Within this view, inhibitory mechanisms are thought to operate selectively: instead of shutting down all responses, they specifically target the response tendencies triggered by irrelevant stimulus features (Ridderinkhof, 2002a, 2002b). At the same time, inhibition does not act in isolation. The inhibitory effort works in parallel with adjustments in the correct pathway, ensuring that both competing tendencies are kept under control until the task-relevant information (i.e., stimulus direction) is ready to be expressed (Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015). This provides an explanation for the slower responses typically observed in conflicting trials: releasing the correct response is briefly delayed until inhibition has done its work, preventing premature or erroneous actions (Burle et al., 2016; van Campen et al., 2014, 2018).

This dynamic is thought to optimize efficiency, consistent with task-goals (e.g., "be as fast and as accurate as possible"), rather than completely suppress the source of conflict (Hübner & Mishra, 2013; Ridderinkhof, 2002a; Ulrich et al., 2015). As a result, information from the automatic route can still affect decision making and subsequent response selection (Ulrich et al., 2015; White et al., 2018). In addition, the suppression mechanism can be altered, for instance through proportion compatibility or response-mapping manipulations (De Jong et al., 1994; Hübner & Töbel, 2019; Ridderinkhof, 2002a), demonstrating its flexibility. Thus, complex stimuli, through their masking features, may alter these dynamics in specific ways by shifting either the strength or the onset of selective suppression.

Distributional results support this possibility. CAF analyses showed that the automatic route was further modulated by complex stimuli, altering the typical pattern and potentially increasing the requirement for earlier and/or stronger engagement of control mechanisms to maintain the efficiency demanded by task instructions. This earlier onset or increased strength of control would reduce interference, consistent with the effects observed among the fastest responses in delta plots.

Converging evidence from prior literature reinforces this view. For instance, some research suggests that the initial automatic impulse triggered by irrelevant information and the onset of suppression can occur very early and in parallel (van Campen et al., 2014, 2018), meaning that the system can counteract interference almost as soon as it arises. Moreover, it has been suggested that the source of these interfering impulses may rise also during early sensory stages, and not only during response-selection (Salzer et al., 2017, 2019). This perspective not only complements the traditional models by proposing that control mechanisms act on impulses that originate as soon as irrelevant features are encoded, but also aligns with the multi-level view of the Stroop effect (Viviani, Visalli, Montefinese, et al., 2024), in which control is thought to unfold along a cascade of control (Banich, 2019).

In addition, the engagement of inhibitory mechanisms has also been proposed in masked priming accounts of the NCE. On one hand, the self-inhibition account argues that the prime itself triggers an early response impulse which, once masked and no longer visible, is automatically and selectively suppressed, sometimes even leading to a

transient activation of the opposite response through lateral inhibition (Eimer & Schlaghecken, 2002).

By contrast, and perhaps more relevant to this work, the mask-triggered inhibition account proposes that the mask actively suppresses the prime-induced response by engaging a selective "emergency brake", with inhibition time-locked to the mask rather than to the prime (Jaśkowski et al., 2008; Jaśkowski & Przekoracka-Krawczyk, 2005; Panis & Schmidt, 2016). According to this account, the inhibitory mechanism requires a strong mask signal, though not necessarily strong masking of the prime (Jaśkowski & Przekoracka-Krawczyk, 2005; Panis & Schmidt, 2016). This specific aspect might explain the absence of differences between level-2 and level-3 arrows in **Study 4**: both target types may have provided comparable signals, despite level-3 producing stronger masking. A similar rationale could be applied to the RCE observed with infinity symbols in Z. Chen et al. (2022).

Overall, the dynamic interplay between inhibition and disinhibition is thought to underlie the NCE. Thus, a comparable process may also help to account for the RCE in the spatial Stroop task.

Building on this reasoning, if the RCE reflects the recruitment of inhibitory mechanisms based on stimulus properties, its expression might depend jointly on the stimulus configuration and the efficiency of the system implementing such processing and control. Thus, a less mature cognitive system should reflect this dynamic, as previously suggested in relation to the masking elements. Accordingly, evidence from developmental research may also provide complementary insights.

For instance, employing a distributional approach, Ambrosi et al. (2020) found that children as young as five years old showed CAF patterns comparable to adults with simple non-social stimuli in the Simon task, but not before adolescence in a color Stroop task. Interestingly, no age-related differences were observed in the general trend of the delta functions. These findings not only validate the use of distributional tools in developmental samples (see also, Ambrosi et al., 2019) but also suggest that control mechanisms underlying response-based and stimulus-based interference develop along different trajectories (Ambrosi et al., 2020; Cragg, 2016).

Thus, the patterns observed with complex stimuli in children may reflect the joint immaturity of inhibitory control and perceptual processing. The standard SCE observed in four-year-old children with complex faces, for example, may correspond to their developmental profile, as inhibitory control mechanisms are not yet fully mature (Ambrosi et al., 2019, 2020; Cao et al., 2013; Macdonald et al., 2014). Without the joint contribution of mature inhibitory control and fully developed complex stimulus processing, even faces tend to elicit a standard SCE. This may explain why, once these mechanisms develop during and after adolescence, gaze stimuli produce an RCE.

A further question is whether inhibition in the RCE reflects a stable mechanism operating across the entire task, or whether it is dynamically recruited on a trial-by-trial basis. The findings suggest that both levels of adjustment may be relevant, though the reversal itself may depend more critically on trial-wise control.

On the one hand, group-level differences in **Study 4** indicate that global strategies can modulate interference, consistent with accounts distinguishing between sustained (global) and reactive (trial-wise) control (Torres-Quesada et al., 2022). Stimuli with clearer access to directional information, such as level-1 arrows and gaze, appeared especially sensitive to these global demands, aligning with proposals that preparatory control is more effective when stimulus characteristics are predictable (Ellinghaus et al., 2024; Hübner & Mishra, 2013).

At the same time, other patterns point to localized, trial-wise adjustments. The RCE persisted for the most complex targets (levels 2 and 3 arrows) regardless of presentation format, and the direction of interference remained stable across blocks (**Study 4**). In addition, both the dual-route framework and masked priming accounts rest on the assumption that the inhibitory mechanism operates on a trial-wise basis (Jaśkowski et al., 2008; Panis & Schmidt, 2016; Ridderinkhof, 2002a, 2002b; Ulrich et al., 2015). Consistent with this assumption, supplemental exploration described in **Appendix F** examined congruency effects within the first 20 trials, including practice trials, across five studies (8 experiments, $N = 231$). The descriptive results revealed a tendency toward reversal dynamics from the first trials. Together, these observations suggest that inhibitory control in the RCE cannot be fully explained by sustained, global adjustments alone.

In this sense, inhibition in the spatial Stroop may reflect a layered control system: global strategies shape overall performance context. At the same time, trial-by-trial adjustments implement the rapid suppression necessary to resolve conflict as it arises, which might be behind the RCE dynamic.

4.2. Toward an Account of the Underlying Dynamics of the RCE

The theoretical contributions outlined above converge on describing the RCE as a multifactorial phenomenon. This raises the question of which underlying mechanisms can best account for how these influences give rise to reversal dynamics. Addressing this issue requires situating the present findings within broader explanatory frameworks. Given that the RCE can be elicited by non-social targets, these frameworks are best approached from domain-general perspectives.

One such account emphasizes the adjustments of attentional focus (Z. Chen et al., 2022). Narrowing the attentional "window" should reduce distractor influence, whereas broadening it may allow irrelevant codes to intrude. Although evidence supports this view for non-spatial interference (**Section 1.4.3.**), it may not fully account for spatially irrelevant codes. Moreover, it does not explain why incongruent trials can be faster and more accurate than congruent trials. If attentional focus simply enhances access to task-relevant information, one would expect reduced interference rather than a reversal, or a clear difference between faces and eyes, since faces should require a greater adjustment. Nevertheless, this account might show some lights for the pattern observed with targets embedded in mosaic backgrounds, where the conflict effect was reduced.

Another framework posits that the RCE reflects two sequential stages (Y. Tanaka et al., 2024, 2025). First, with complex targets, the extraction of directional information is delayed, allowing spatial codes to dissipate. Once this interference has decayed, reversal dynamics emerge through inhibitory processes. Yet, as discussed in **Section 4.1.2.**, increased difficulty alone is insufficient: surrounding features must also interact directly with task-relevant information to generate the reversal, rather than being treated as neutral background segregation. Moreover, while the dual-stage account highlights inhibitory control, it assumes inhibition occurs only after target–background segregation (Y. Tanaka et al., 2024). By contrast, evidence across studies suggests that inhibition may act earlier, with its strength and/or onset varying as a function of stimulus features, aligning more closely with masked priming accounts.

To address these gaps, the present work proposes a reinterpretation of the integrative account within the dual-route framework. This theoretical model has already been applied to explain interference and control dynamics in conflict tasks (**Section**

1.4.4.), providing a stable architecture that allows the operationalization of different factors which may underlie reversal dynamics. Within this framework, and based on the observations discussed above, one possible interpretation is that the RCE reflects the interaction of stimulus-related features, task dynamics, and control mechanisms, with their relative weighting varying across conditions. Such shifts in weighting could account not only for the emergence of the phenomenon but also for the observed specific modulations.

As described in **Section 1.4.4.**, the dual-route framework assumes two parallel processing streams: a fast automatic route that reflexively activates responses based on irrelevant features such as spatial location, and a slower controlled route that processes task-relevant information (e.g., target direction) in accordance with instructions. Typically, congruent trials benefit from the convergence of both routes, whereas incongruent trials face early interference from the automatic route until inhibition suppresses it and the controlled route guides the response.

The RCE inverts this pattern. Increasing perceptual complexity seems to alter the balance between routes, when irrelevant visual information alongside spatial interference directly interacts with relevant codes by (a) amplifying early automatic activation and (b) disrupting the controlled route's access to task-relevant information. This interpretation aligns with the view that some task-irrelevant information may briefly spill over into decision-making driven by the controlled route (Ulrich et al., 2015). In parallel, as pointed in the previous section, the system may recruit stronger and earlier inhibition, adapted to stimulus-specific activations, to counteract premature responses. Together, these factors could reverse the relative efficiency of congruent and incongruent trials.

More specifically, a tentative mechanism can be outlined, drawing on the previous interplay between inhibition and response selection described in masked priming studies (e.g., Jaśkowski & Przekoracka-Krawczyk, 2005; Schmidt et al., 2022; Verleger et al., 2004) and paralleling the second stage of the dual-stage account (Y. Tanaka et al., 2024, 2025). On incongruent trials, the automatic route activates the incorrect response. However, because perceptual complexity accelerates inhibitory control, this response is quickly suppressed. By the time directional information becomes available via the controlled route, it can proceed without interference as the only viable option. On congruent trials,

in contrast, the automatic route activates the correct response, but this response is also subjected to early inhibition. When the directional code arrives, the system must first release the inhibition before execution, producing delays and elevated error rates among the fastest responses.

This account aligns with distributional findings: CAFs show reduced accuracy for both congruent and incongruent trials at the fastest responses, with congruent trials more affected; delta functions show attenuated or reversed interference among early responses, with the reversal consolidating at middle quantiles. Such patterns are difficult to reconcile with accounts based solely on perceptual salience or social processes, but fit a mechanism where automatic activation and inhibitory dynamics, modulated by perceptual features of stimuli, jointly shape performance.

Finally, this perspective can be extended to gaze stimuli. Eyes and faces are perceptually complex and contain overlapping features that, in appropriate conditions, act as embedded masks, amplifying inhibitory recruitment. At the same time, gaze may also engage socially specific mechanisms that further intensify those patterns at slower responses, and aspect that required further examination.

Crucially, the reinterpretation of the RCE within the dual-route framework is not intended as a purely theoretical exercise but as a set of testable predictions. Each proposed component, whether early amplification of automatic activation, trial-wise inhibitory recruitment, or the modulatory role of perceptual complexity, can be examined through different tools and experimental settings. In this sense, the present account provides not only an interpretation of the RCE but also a concrete basis for empirical validation.

4.3. Future Directions

The present work clarifies the contribution of non-social mechanisms to the RCE, but it also points to findings that require further corroboration and to questions that remain open. In particular, future studies should investigate how specific variations in perceptual complexity, temporal dynamics, and social relevance shape both the emergence and the trajectory of the reversal.

A first line of interesting future research concerns the systematic manipulation of perceptual complexity. Based on the findings of **Study 4**, future work should expand this approach by varying the type, structure, and timing of masks, as well as their similarity to the target. Such manipulations would also be in line with masked priming research (e.g., Jaśkowski & Przekoracka-Krawczyk, 2005), and could clarify whether the RCE depends on specific visual configurations (e.g., arrow-like vs. non–arrow-like masks) or reflects a more general principle of hindering access to task-relevant information.

A second direction is to examine the temporal dynamics of conflict resolution more directly. Distributional analyses in the present studies suggest that early inhibitory recruitment plays a key role in shaping reversal effects. This hypothesis could be tested using methods with higher temporal resolution, such as electroencephalography (EEG), to trace the onset and time course of automatic activation and inhibition. For instance, EEG evidence suggests that distractor inhibition underlies conflict regulation in Simon conflicts (Lee et al., 2025), an approach that could be applied to the spatial Stroop.

Moreover, Marotta et al. (2019) already provide an important baseline with electrophysiological data (**Section 1.4.3.**) for testing whether masked arrows elicit the same patterns as gaze stimuli. An interesting addition would be to include whole-face stimuli, which in the present studies produced earlier and stronger modulations in the CAF compared to isolated eyes. Their inclusion could also enhance the amplitude and/or latencies of early ERP components (e.g., P1 and N170 in Miki et al., 2015 & Taylor et al., 2004), potentially revealing clearer dissociations across conditions. Furthermore, analyzing lateralized readiness potentials, following approaches from masked priming studies (e.g., Jaśkowski et al., 2008) and location-based tasks (e.g., experiment 4 in De Jong et al., 1994) could offer a more detailed understanding of the initial phases of response selection based on stimulus position.

In the same line, electromyography (EMG) combined with transcranial magnetic stimulation (TMS) has been used to disentangle the temporal interplay between the expression and suppression of initial automatic impulses during conflict (van Campen et al., 2014, 2018). Applying these techniques to the spatial Stroop could provide further evidence about the dynamics of the automatic route along with the response capture mechanism.

A third avenue concerns developmental trajectories. As described in previous sections, Aranda-Martín et al. (2022) observed a distinctive developmental pattern of the RCE, raising the question of whether masked arrows would follow a similar course. This question could be addressed using distributional tools. CAF analyses have revealed age-related differences across tasks such as the Simon, color Stroop, and Flanker, all using simple non-social stimuli (Ambrosi et al., 2020). Applying this tool to compare complex versus simple directional stimuli could advance our understanding of how stimulus complexity shapes developmental profiles in terms of interference and control. Moreover, while delta patterns show little variation across age for simple stimuli (Ambrosi et al., 2020), examining complex targets may reveal additional dynamics, as the RCE might involve processes not involved within the SCE.

In this same line, future research could directly test the proposed disruption of holistic processing as a facilitator of a "masking effect" in social stimuli. This could be achieved, for instance, through electrophysiological measures targeting early components typically associated with face processing (e.g., Taylor et al., 2004), combined with manipulations of task demands (explicit versus implicit) as in Narganes-Pineda, Chica, et al. (2023). Such manipulations can modulate the mode of face processing in recognition tasks (Taylor et al., 2004), and might help to further clarify the underlying mechanism within the spatial Stroop.

Moreover, comparing masked arrows and faces across age groups could elucidate the developmental trajectory required for the masking effect to emerge and examine whether social stimuli differ due to humans' early face expertise. Finally, because the mask's effectiveness likely depends on its perceptual overlap with the target, it may vary with the development of configural and featural processing, which has been shown to change with age in object recognition tasks (e.g., Jüttner et al., 2013). Consequently, these

developmental changes could critically determine when and how reversal dynamics arise.

A fourth direction is to further address the relationship between social and non-social accounts. Although perceptual complexity can generate reversals with arrows, gaze stimuli continue to show distinctive patterns, particularly in relation to emotional expressions and social traits. A suitable strategy might be to place social and non-social stimuli along a continuum of perceptual and communicative complexity, examining how their position on this continuum shapes the emergence of reversal effects. This approach would help disentangle the relative weight of social meaning and perceptual constraints in the RCE.

Finally, future studies could adopt a computational modeling perspective to formalize the mechanisms proposed here. Within the dual-route framework, the diffusion model for conflict tasks (DMC; Ulrich et al., 2015) has captured many distributional patterns in flanker, Simon and Stroop tasks. However, as the authors themselves noted, reversals of the congruency effect are theoretically challenging: the basic model can only generate them under extra assumptions such as explicit inhibitory processes (as assumed in the present work). More recently, the revised diffusion model for conflict tasks (RDMC; Lee & Sewell, 2024) has been proposed as a non-inhibitory alternative that can account for negative congruency effects by modeling dynamic attentional shifts between automatic and controlled routes. Such models could simulate how perceptual difficulty, automatic activation, and the rate of relevant information processing produce reversal dynamics, thereby testing the plausibility of the mechanisms outlined in this thesis and generating new quantitative predictions.

Taken together, these directions highlight the importance of approaching the RCE as a multi-factorial phenomenon. By combining experimental manipulations, distributional analyses, neural methods, and computational modeling, future research can move toward a more comprehensive understanding of how different factors interact to shape attentional control in spatial interference tasks.

4.4. Concluding Remarks

The present thesis examined the RCE across a series of distributional analyses and experimental manipulations, with the aim of clarifying its boundary conditions and underlying mechanisms. Across four studies, the findings converge on a central insight: the RCE is not exclusive to gaze but a multifactorial outcome shaped by the interplay of perceptual complexity, temporal dynamics, control mechanisms and the system itself.

By reanalyzing large datasets, **Studies 1** and **2** established a robust profile of the RCE across social and non-social stimuli. They showed that gaze consistently produced reversal-like dynamics from early latencies, while arrows adhered to the typical spatial interference effect. These analyses highlighted the value of conditional accuracy functions and delta plots for uncovering dissociations that remain undetected in mean-based measures, and demonstrated that the RCE is sensitive to both stimulus properties and task demands.

To further investigate the RCE, **Studies 3** and **4** tested whether non-social stimuli could reproduce reversal-like outcomes. The results showed that perceptual manipulations, particularly visual masking, allow arrows to mimic patterns typically observed with gaze. In **Study 4,** masking arrows with oblique line elements produced robust reversals, with accuracy drops for congruent trials and a temporal unfolding of interference equivalent to that observed with gaze stimuli. This provides a bridge between social and non-social accounts: what gaze provides naturally through its intrinsic perceptual complexity (the interplay of sclera, iris, and surrounding facial features), arrows can reproduce artificially when embedded in specific visual contexts.

This convergence points to a multi-layered and interactive account of the RCE. At its most superficial level, the reversal can be understood as the consequence of hindering directional information through visual masking, which elicits compensatory modulations within the control system.

At a deeper level, however, the critical factor is not masking per se, but the presence of non-neutral visual inputs that actively interact with directional signals, reshaping the dynamics of conflict resolution. When these non-neutral elements are configured to form a compound stimulus—integrated enough to be processed as a single

object yet sufficiently independent to generate their own competing signals—they can induce a "masking effect" that modulates how control mechanisms unfold over time.

Beyond this, the effect depends on how the perceptual-attentional systems weights and integrate the signals generated by each component. For the masking effect to emerge, the system must flexibly allocate processing resources across partially competing inputs, balancing speed and accuracy while regulating irrelevant information that, as shown here, is not limited to spatial features. In this context, the task itself acts as a node within the network: its temporal demands and response instructions (i.e., focus on direction while ignoring position) facilitate the rupture between target and surrounding elements, prompting the recruitment of inhibitory control in specific ways.

Altogether, the RCE can be conceived as the emergent outcome of three interacting nodes—the stimulus, the task, and the system—each contributing weighted influences that shape the resulting interference pattern. When the system fails to integrate or inhibit efficiently (e.g., in younger participants or under reduced control capacity), these weightings shift, producing variations in the direction and magnitude of the effect across contexts and stimuli.

Taken together, the results reframe the RCE as a marker of how perceptual complexity, control mechanisms, task demands and the system itself interact to shape attentional processing. By situating gaze and arrows along a continuum of informational richness and interference, this thesis advances an integrative framework in which social and non-social factors are not competing explanations but complementary dimensions of the same underlying processes. More broadly, the work contributes to debates in attention research by demonstrating the value of distributional methods for tracing temporal profiles of conflict and by showing how classical paradigms such as the spatial Stroop can disentangle perceptual from social influences.

In conclusion, this thesis contributes to connecting social and non-social accounts of the RCE by demonstrating that perceptual manipulation can induce reversal effects with non-social stimuli. At the same time, much remains to be clarified, and the present findings suggest new directions for future investigation, in how the cognitive system integrates perceptual complexity and social processing in the regulation of attention.

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APPENDICES

Appendix A. Supplemental Materials for Study 1

Impact of target presentation design on model fitting

To assess the impact of target presentation method (i.e., within-block vs. between-blocks), we combined data from the studies by Hemmerich et al. (2022, experiments 1 & 2) and Bonventre & Marotta (2023, experiment 2), which comprise 3 experiments using within-block target presentations. In contrast, the between-block design was used in the studies by Marotta et al. (2018, 2019), and Bonventre & Marotta (2023, experiment 1), totaling 3 datasets. All these studies conducted arrow vs. eye-gaze comparisons, ensuring methodological consistency.

Linear mixed models were employed to contrast the saturated and full models against the null model. Both the saturated and full models included target type, congruency, bin, and their interactions as fixed effects, with participants nested within studies as random effects. The saturated model included the block design condition (within vs. between) as an additional predictor: *Acc ~ TargetType * Congruency * Bin + BlockDesign + (1|Study:id)*. The results, presented in Table 1, revealed that incorporating the 'BlockDesign' predictor did not significantly improve the fit.

Table 1. Target type block presentation design analysis

Model	AIC	BIC	χ^2	Df.	p-value
Saturated	-8 451	-8 310	0.75	1	0.388
Full	-8 453	-8 317	642.84	19	< .0001
Null	-7 848	-7 829	-	-	-

Note. The comparisons were tested using the likelihood ratio test, in a sequential manner, Saturated vs. Full, and Full vs. Null models.

Trimming procedure

For the trimming procedure, we followed the same cutoff criterion used in most original studies, excluding reaction times shorter than 200ms and longer than 1300ms (Table 2). This method was applied across all studies, including Dalmaso et al. (2023), even though the original study utilized a trimming procedure based on 3 standard

deviations (SDs). Additionally, our trimming procedure accounted for both correct and incorrect responses.

Table 2. Error rates, remaining trials and trials removed by study

Study	Incorrect trials (%)	Remaining trials (%)	Trials removed (%)
Torres-Marín et al. (2017), experiments 1 & 2	5.44%; 4.95%	98.10%; 98.95%	.01% (*<200*), 1.15% (*zero*), .74% (*>1300*); .01% (*<200*), 1.12% (*zero*), .92% (*>1300*)
Marotta et al. (2018)	3.15%	99.65%	.01% (*<200*), .06% (*zero*), .28% (*>1300*)
Marotta (Unpublished)	2.03%	99.49%	.00% (*<200*), .14% (*zero*), .37% (*>1300*)
Marotta et al. (2019)	3.21%	99.32%	.00% (*<200*), .30% (*zero*), .38% (*>1300*)
Hemmerich et al. (2022), experiments 1 & 2	2.23%; 4.45%	99.14%; 98.88%	.00% (*<200*), .20% (*zero*), .66% (*>1300*); .00% (*<200*), .53% (*zero*), .59% (*>1300*)
Narganes-Pineda et al. (2022), experiment 1	2.66%	99.17%	.02% (*<200*), .31% (*zero*), .50% (*>1300*)
Marotta et al. (2022)	5.37%	99.00%	.03% (*<200*), .16% (*zero*), .81% (*>1300*)
Bonventre & Marotta (2023), experiments 1 & 2	2.25%; 3.08%	99.61%; 99.37%	.00% (*<200*), .00% (*zero*), .39% (*>1300*); .00% (*<200*), .06% (*zero*), .57% (*>1300*)
Ishikawa et al. (2022), experiments 1 & 3	3.99%; 4.14%	99.13%; 99.36%	.11% (*<200*), .00% (*zero*), .76% (*>1300*); .32% (*<200*), .00% (*zero*), .32% (*>1300*)
Tanaka et al. (2023a), experiments 1A & 1B	5.13%; 4.20%	99.20%; 99.84%	.08% (*<200*), .16% (*zero*), .56% (*>1300*); .00% (*<200*), .08% (*zero*), .08% (*>1300*)
Dalmaso et al. (2023)	2.69%	99.71%	.01% (*<200*), .19% (*zero*), .09% (*>1300*)

Note. The reported error rates were calculated after the trimming procedure. The reported values are separated by a semicolon for studies with more than one experiment. The column 'Remaining trials' represents the percentage of correct and incorrect responses after the trimming procedure. The column 'Trials removed' represents the percentage of trials faster than 200ms (*<200*), without response (*zero)*, and slower than 1300ms (*>1300*).

The results showed that incorrect trials after trimming ranged from 2.03% to 5.44%. The remaining trials, both correct and incorrect, ranged from 98.10% to 99.85%. This aligns with the recommendations of Ülrich and Miller (1994), which suggest removing less than 0.5% of the data. We also reported separately trials without response (0.00% to 1.15%) and those faster than 200ms (0.00% to 0.11%). Trials slower than 1300ms ranged from 0.08% to 0.92%. Importantly, 7 datasets did not have trials under 200ms, 5 datasets had less than 0.05%, and the remaining datasets showed no trials under 200ms over 0.11%, minimizing the risk of losing important information since typical modulations in CAF literature are within the fastest responses (e.g., Amborsi et al., 2019; Ülrich et al., 2015). Consequently, the data removal was minimal, as recommended (e.g., Ratcliff, 1993; Ülrich & Miller, 1994).

In addition, the same analyses were performed by removing only trials without response. Models MA and MB showed consistent patterns throughout the distribution. Model MC displayed similar patterns, although the contrast between bin 3 and bin 4 in congruent trials was not significant. This change does not affect our conclusions. Although these results are not reported, the untrimmed datasets and the script are available on the OSF webpage (see data availability statement).

Linear-Mixed model and beta regression comparisons

We evaluated linear mixed modeling (LMM) against beta regression (Ferrari & Cribari-Neto, 2004) using the k-fold cross-validation method (Geisser, 1975), employing 10 folds. We compared the mean squared errors (MSEs) across both methods for each full model. For LMM, we utilized the lme4 package, and for beta regression, the glmmTMB package (Bates et al., 2015; Brooks et al., 2017, respectively). In all three comparisons, LMM exhibited lower MSE values: $MSE\text{-}MA_{LMM} = .008093$ *vs* $MSE\text{-}MA_{beta} = .009515$; $MSE\text{-}MB_{LMM} = .008094$ *vs* $MSE\text{-}MB_{beta} = .009518$; $MSE\text{-}MC_{LMM} = .01229$ *vs* $MSE\text{-}MC_{beta} = .01061$.

Hierarchical comparison against the Null Model

To identify the best-fitting models and their closest competitors for further comparisons, we employed the likelihood ratio test along with the AIC and BIC criteria. We systematically assessed the models, starting from the most complex (the Full model)

and progressing to the simplest (the null model), in a sequential manner (Table 3): Full versus Level1, followed by Level1 versus Level2, and so forth. The criterion for simplifying the Full model was based on the interaction among the three factors (i.e., target type, congruency, bin); thus, the Full model accounted for the three-way interaction. The Level1 model considered the two-way interactions between target type and congruency, and between congruency and bin, while the Level2 model included only the interaction between target type and congruency. Had any model not achieved a significant result, we would have added more levels, but this was not necessary.

Additionally, we evaluated various random parameters, considering the inherent grouping structure and strategies for improving model fit (Barr, 2013; Barr et al., 2013; Meteyard & Davies, 2020). Participants, the basic unit of analysis, were modeled as nested within studies. The R syntaxis for nested designs is '*(1|Study/id)*' or its alternative '*(1|Study) + (1|Study:id)*', as described in Bates et al. (2015, Table 2). However, the variance for the inclusion of intercept by Study -i.e., *(1|Study)*- was zero, producing a singular fit. Therefore, we used a crossed effects syntax as suggested in Schielzeth & Nakagawa (2013): "Nested effects can usually be fitted using the syntax for crossed effects if the coding reflects implicit nesting" (p. 21).

The same implicit nesting considerations were applied to the other random parameters. Target type conditions were treated as unique to each study, allowing for modeling variations between studies based on target type -i.e., *(1|Study:TargetType*)-, while also considering each study's unique structure regarding congruency and bin factors -*i.e., (Study:TargetType:Congruency:Bin)*-. Similarly, for model MC, introducing a random intercept for each study led to zero variance. In addition, the studies included were methodologically similar, prompting a simplification of the model to include only a random intercept for participants within each study.

Table 3. Hierarchical comparison levels within each model.

Levels	Fixed	Random
Full	*Acc ~ TargetType * Congruency * Bin*	*+ (1|Study:id) + (1|Study:TargetType) + (1|Study:TargetType:Congruency:Bin)* *MC: + (1|Study:id)*
Level1	*Acc ~TargetType * Congruency + Congruency * Bin*	
Level2	*Acc ~ TargetType * Congruency*	
Null	*Acc ~ 1*	

Note. For model MC, the predictor 'TargetType' was replaced by 'Expression'.

The results of the hierarchical comparison are described in Table 4. For model MA, the comparison among the Full (best fit) and Level1 models (second-best fit) revealed a significant improvement, $\chi^2\ (8) = 87.12$, $p < .0001$, with lower AIC and BIC values as observed in below. In the case of model MB, the comparison between the Full and Level1 models (best and second-best fit, respectively), revealed, as well a better fit, when including the three-way interaction, $\chi^2\ (16) = 93.39$, $p < .0001$. For model MC, the Level1 and Level2 models were identified as the best and second-best fits, respectively. The Level1 model showed an improvement in AIC and BIC compared to the Level2 model, with the likelihood ratio test indicating a significant enhancement in fit, $\chi^2\ (8) = 827.31$, $p < .0001$.

Table 4. Results of the hierarchical comparisons between modelling levels by model.

Model	Level	AIC	BIC	χ^2	Df.	p-value
MA	Full	-23 749	-23 571	87.12	8	< .0001
	Level1	-23 678	-23 559	210.39	8	< .0001
	Level2	-23 483	-23 424	18.99	3	< .001
	Null	-23 470	-23 433	-	-	-
MB	Full	-23 737	-23 485	93.39	16	< .0001
	Level1	-23 675	-23 542	211.31	8	< .0001
	Level2	-23 480	-23 406	19.84	5	0.001
	Null	-23 470	-23 433	-	-	-
MC	Full	-9 703	-9 356	32.83	32	0.426
	Level1	-9 734	-9 600	827.31	8	< .0001
	Level2	-8 923	-8 843	132.80	9	< .0001
	Null	-8 808	-8 788	-	-	-

Note. The comparisons were performed using the likelihood ratio test, AIC and BIC criteria, in a hierarchical fashion.

Contrast analyses models MA and MB

The results below reported significant three-way interactions in models MA and MB. Table 5 describes congruency contrasts by Bin and target type, while Table 6 presents contrasts between Bins by congruency and target type.

Table 5. Contrasts of congruency (congruent vs. incongruent) by Bin and target type

Model MA							
Target Type	**Bin**	**Estimate**	**SE**	**LCL**	**UCL**	**t ratio**	**p value**
Social	1	-0.014	0.007	-0.03	0.00	-1.87	0.063
	2	**-0.025**	**0.007**	**-0.04**	**-0.01**	**-3.28**	**0.001**
	3	-0.003	0.007	-0.02	0.01	-0.38	0.706
	4	0.001	0.007	-0.01	0.02	0.13	0.896
	5	0.010	0.007	-0.01	0.02	1.27	0.205
Non-social	**1**	**0.105**	**0.009**	**0.09**	**0.12**	**11.28**	**< .0001**
	2	0.016	0.009	0.00	0.03	1.77	0.078
	3	0.002	0.009	-0.02	0.02	0.24	0.808
	4	-0.002	0.009	-0.02	0.02	-0.17	0.864
	5	0.012	0.009	-0.01	0.03	1.27	0.206
Model MB							
Target Type	**Bin**	**Estimate**	**SE**	**LCL**	**UCL**	**t ratio**	**p value**
Face	**1**	**-0.037**	**0.011**	**-0.06**	**-0.01**	**-3.24**	**0.001**
	2	**-0.029**	**0.011**	**-0.05**	**-0.01**	**-2.54**	**0.012**
	3	0.000	0.011	-0.02	0.02	0.00	0.998
	4	-0.001	0.011	-0.02	0.02	-0.13	0.896
	5	0.009	0.011	-0.01	0.03	0.80	0.423
Eyes	1	0.004	0.010	-0.02	0.02	0.41	0.679
	2	**-0.021**	**0.010**	**-0.04**	**0.00**	**-2.07**	**0.040**
	3	-0.005	0.010	-0.03	0.02	-0.50	0.618
	4	0.003	0.010	-0.02	0.02	0.30	0.766
	5	0.010	0.010	-0.01	0.03	0.97	0.335
Arrows	**1**	**0.104**	**0.009**	**0.09**	**0.12**	**11.08**	**< .0001**
	2	0.016	0.009	0.00	0.03	1.74	0.084
	3	0.002	0.009	-0.02	0.02	0.24	0.813
	4	-0.002	0.009	-0.02	0.02	-0.17	0.866
	5	0.012	0.009	-0.01	0.03	1.26	0.211

Note. LCL and UCL represent the lower and upper confidence limits, respectively, of the 95% confidence intervals. Significant results are in bold.

Table 6. Contrasts between Bins by target type and congruency

Model MA							
Target Type - congruency	**Bin Contrast**	**Estimate**	**SE**	**LCL**	**UCL**	**t ratio**	**p value**
Social – congruent	**1-2**	**-0.065**	**0.007**	**-0.09**	**-0.04**	**-8.65**	**< .0001**
	1-3	**-0.087**	**0.007**	**-0.11**	**-0.07**	**-11.61**	**< .0001**
	1-4	**-0.092**	**0.007**	**-0.11**	**-0.07**	**-12.29**	**< .0001**
	1-5	**-0.090**	**0.007**	**-0.11**	**-0.07**	**-11.98**	**< .0001**
	2-3	**-0.022**	**0.007**	**-0.04**	**0.00**	**-2.96**	**0.028**
	2-4	**-0.027**	**0.007**	**-0.05**	**-0.01**	**-3.64**	**0.003**
	2-5	**-0.025**	**0.007**	**-0.05**	**0.00**	**-3.32**	**0.009**
	3-4	-0.005	0.007	-0.03	0.02	-0.68	0.960
	3-5	-0.003	0.007	-0.02	0.02	-0.36	0.996
	4-5	0.002	0.007	-0.02	0.02	0.32	0.998
Social – incongruent	**1-2**	**-0.075**	**0.007**	**-0.10**	**-0.05**	**-10.07**	**< .0001**
	1-3	**-0.076**	**0.007**	**-0.10**	**-0.06**	**-10.12**	**< .0001**
	1-4	**-0.077**	**0.007**	**-0.10**	**-0.06**	**-10.29**	**< .0001**
	1-5	**-0.066**	**0.007**	**-0.09**	**-0.05**	**-8.84**	**< .0001**
	2-3	0.000	0.007	-0.02	0.02	-0.05	1.000
	2-4	-0.002	0.007	-0.02	0.02	-0.23	0.999
	2-5	0.009	0.007	-0.01	0.03	1.23	0.733
	3-4	-0.001	0.007	-0.02	0.02	-0.17	1.000
	3-5	0.010	0.007	-0.01	0.03	1.29	0.701
	4-5	0.011	0.007	-0.01	0.03	1.46	0.591
Non-social - congruent	1-2	0.001	0.009	-0.03	0.03	0.06	1.000
	1-3	0.002	0.009	-0.02	0.03	0.20	1.000
	1-4	0.001	0.009	-0.02	0.03	0.11	1.000
	1-5	0.003	0.009	-0.02	0.03	0.35	0.997
	2-3	0.001	0.009	-0.02	0.03	0.14	1.000
	2-4	0.001	0.009	-0.03	0.03	0.05	1.000
	2-5	0.003	0.009	-0.02	0.03	0.29	0.998
	3-4	-0.001	0.009	-0.03	0.02	-0.09	1.000
	3-5	0.001	0.009	-0.02	0.03	0.15	1.000
	4-5	0.002	0.009	-0.02	0.03	0.24	0.999
Non-social - incongruent	**1-2**	**-0.088**	**0.009**	**-0.11**	**-0.06**	**-9.45**	**< .0001**
	1-3	**-0.101**	**0.009**	**-0.13**	**-0.07**	**-10.84**	**< .0001**
	1-4	**-0.105**	**0.009**	**-0.13**	**-0.08**	**-11.34**	**< .0001**
	1-5	**-0.090**	**0.009**	**-0.12**	**-0.06**	**-9.66**	**< .0001**
	2-3	-0.013	0.009	-0.04	0.01	-1.39	0.637
	2-4	-0.018	0.009	-0.04	0.01	-1.89	0.327
	2-5	-0.002	0.009	-0.03	0.02	-0.21	1.000
	3-4	-0.005	0.009	-0.03	0.02	-0.50	0.987

	3-5	0.011	0.009	-0.01	0.04	1.18	0.764
	4-5	0.016	0.009	-0.01	0.04	1.68	0.449

Model MB

Target Type - congruency	Bin Contrast	Estimate	SE	LCL	UCL	t ratio	p value
Face / congruent	**1-2**	**-0.076**	**0.011**	**-0.11**	**-0.05**	**-6.74**	**< .0001**
	1-3	**-0.101**	**0.011**	**-0.13**	**-0.07**	**-8.97**	**< .0001**
	1-4	**-0.104**	**0.011**	**-0.14**	**-0.07**	**-9.18**	**< .0001**
	1-5	**-0.103**	**0.011**	**-0.13**	**-0.07**	**-9.13**	**< .0001**
	2-3	-0.025	0.011	-0.06	0.01	-2.22	0.176
	2-4	-0.028	0.011	-0.06	0.00	-2.43	0.111
	2-5	-0.027	0.011	-0.06	0.00	-2.39	0.124
	3-4	-0.002	0.011	-0.03	0.03	-0.21	1.000
	3-5	-0.002	0.011	-0.03	0.03	-0.16	1.000
	4-5	0.001	0.011	-0.03	0.03	0.05	1.000
Face / incongruent	**1-2**	**-0.068**	**0.011**	**-0.10**	**-0.04**	**-6.05**	**< .0001**
	1-3	**-0.065**	**0.011**	**-0.10**	**-0.03**	**-5.73**	**< .0001**
	1-4	**-0.069**	**0.011**	**-0.10**	**-0.04**	**-6.07**	**< .0001**
	1-5	**-0.058**	**0.011**	**-0.09**	**-0.03**	**-5.09**	**< .0001**
	2-3	0.004	0.011	-0.03	0.03	0.31	0.998
	2-4	0.000	0.011	-0.03	0.03	-0.03	1.000
	2-5	0.011	0.011	-0.02	0.04	0.96	0.874
	3-4	-0.004	0.011	-0.04	0.03	-0.34	0.997
	3-5	0.007	0.011	-0.02	0.04	0.64	0.968
	4-5	0.011	0.011	-0.02	0.04	0.98	0.862
Eyes / congruent	**1-2**	**-0.056**	**0.010**	**-0.08**	**-0.03**	**-5.43**	**< .0001**
	1-3	**-0.075**	**0.010**	**-0.10**	**-0.05**	**-7.35**	**< .0001**
	1-4	**-0.083**	**0.010**	**-0.11**	**-0.05**	**-8.07**	**< .0001**
	1-5	**-0.079**	**0.010**	**-0.11**	**-0.05**	**-7.69**	**< .0001**
	2-3	-0.020	0.010	-0.05	0.01	-1.92	0.308
	2-4	-0.027	0.010	-0.06	0.00	-2.64	0.066
	2-5	-0.023	0.010	-0.05	0.01	-2.26	0.161
	3-4	-0.007	0.010	-0.04	0.02	-0.72	0.952
	3-5	-0.003	0.010	-0.03	0.02	-0.34	0.997
	4-5	0.004	0.010	-0.02	0.03	0.38	0.996
Eyes / incongruent	**1-2**	**-0.081**	**0.010**	**-0.11**	**-0.05**	**-7.91**	**< .0001**
	1-3	**-0.085**	**0.010**	**-0.11**	**-0.06**	**-8.26**	**< .0001**
	1-4	**-0.084**	**0.010**	**-0.11**	**-0.06**	**-8.19**	**< .0001**
	1-5	**-0.073**	**0.010**	**-0.10**	**-0.04**	**-7.14**	**< .0001**
	2-3	-0.004	0.010	-0.03	0.02	-0.35	0.997
	2-4	-0.003	0.010	-0.03	0.03	-0.27	0.999
	2-5	0.008	0.010	-0.02	0.04	0.77	0.938

	3-4	0.001	0.010	-0.03	0.03	0.08	1.000
	3-5	0.012	0.010	-0.02	0.04	1.13	0.793
	4-5	0.011	0.010	-0.02	0.04	1.05	0.832
Arrows – congruent	1-2	0.000	0.009	-0.03	0.03	0.05	1.000
	1-3	0.002	0.009	-0.02	0.03	0.19	1.000
	1-4	0.001	0.009	-0.02	0.03	0.10	1.000
	1-5	0.003	0.009	-0.02	0.03	0.34	0.997
	2-3	0.001	0.009	-0.02	0.03	0.14	1.000
	2-4	0.000	0.009	-0.03	0.03	0.05	1.000
	2-5	0.003	0.009	-0.02	0.03	0.29	0.999
	3-4	-0.001	0.009	-0.03	0.03	-0.09	1.000
	3-5	0.001	0.009	-0.02	0.03	0.15	1.000
	4-5	0.002	0.009	-0.02	0.03	0.23	0.999
Arrows – incongruent	**1-2**	**-0.087**	**0.009**	**-0.11**	**-0.06**	**-9.29**	**< .0001**
	1-3	**-0.100**	**0.009**	**-0.13**	**-0.07**	**-10.65**	**< .0001**
	1-4	**-0.105**	**0.009**	**-0.13**	**-0.08**	**-11.15**	**< .0001**
	1-5	**-0.089**	**0.009**	**-0.12**	**-0.06**	**-9.49**	**< .0001**
	2-3	-0.013	0.009	-0.04	0.01	-1.36	0.653
	2-4	-0.017	0.009	-0.04	0.01	-1.85	0.346
	2-5	-0.002	0.009	-0.03	0.02	-0.20	1.000
	3-4	-0.005	0.009	-0.03	0.02	-0.49	0.988
	3-5	0.011	0.009	-0.01	0.04	1.17	0.771
	4-5	0.016	0.009	-0.01	0.04	1.66	0.463

Note. LCL and UCL represent the lower and upper confidence limits, respectively, of the 95% confidence intervals. Significant results are in bold.

Contrast analyses model MC

Table 7 presents the results of the congruency contrasts by expression and by bin for model MC. Table 8 reports contrasts between bins by congruency, and Table 9 displays the results of contrasts between expressions by congruency.

Table 7. Contrasts of congruency by expression and by Bins of Model MC.

Congruency contrasts by expression						
Expression	**Estimate**	**SE**	**LCL**	**UCL**	**t ratio**	**p value**
anger	**-0.036**	**0.006**	**-0.05**	**-0.02**	**-5.97**	**< .0001**
fear	**-0.018**	**0.006**	**-0.03**	**-0.01**	**-2.97**	**0.003**
happy	**-0.037**	**0.006**	**-0.05**	**-0.03**	**-6.23**	**< .0001**
neutral	**-0.013**	**0.006**	**-0.02**	**0.00**	**-2.19**	**0.029**
sad	**-0.028**	**0.006**	**-0.04**	**-0.02**	**-4.67**	**< .0001**
Congruency contrasts by Bin						

Bin	Estimate	SE	LCL	UCL	t ratio	p value
1	**-0.091**	**0.006**	**-0.10**	**-0.08**	**-15.36**	**< .0001**
2	**-0.041**	**0.006**	**-0.05**	**-0.03**	**-6.96**	**< .0001**
3	**-0.017**	**0.006**	**-0.03**	**-0.01**	**-2.90**	**0.004**
4	0.003	0.006	-0.01	0.02	0.57	0.566
5	**0.016**	**0.006**	**0.00**	**0.03**	**2.61**	**0.009**

Note. LCL and UCL represent the lower and upper confidence limits, respectively, of the 95% confidence intervals. Significant results are in bold.

Table 8. Contrasts between Bins by congruency of model MC

Model MC							
Congruency	**Bin Contrast**	**Estimate**	**SE**	**LCL**	**UCL**	**t ratio**	**p value**
congruent	**1-2**	**-0.099**	**0.006**	**-0.12**	**-0.08**	**-16.67**	**< .0001**
	1-3	**-0.125**	**0.006**	**-0.14**	**-0.11**	**-20.94**	**< .0001**
	1-4	**-0.142**	**0.006**	**-0.16**	**-0.13**	**-23.88**	**< .0001**
	1-5	**-0.139**	**0.006**	**-0.16**	**-0.12**	**-23.38**	**< .0001**
	2-3	**-0.025**	**0.006**	**-0.04**	**-0.01**	**-4.27**	**< .0001**
	2-4	**-0.043**	**0.006**	**-0.06**	**-0.03**	**-7.21**	**< .0001**
	2-5	**-0.040**	**0.006**	**-0.06**	**-0.02**	**-6.71**	**< .0001**
	3-4	**-0.018**	**0.006**	**-0.03**	**0.00**	**-2.94**	**0.027**
	3-5	-0.015	0.006	-0.03	0.00	-2.44	0.105
	4-5	0.003	0.006	-0.01	0.02	0.50	0.987
incongruent	**1-2**	**-0.049**	**0.006**	**-0.07**	**-0.03**	**-8.27**	**< .0001**
	1-3	**-0.050**	**0.006**	**-0.07**	**-0.03**	**-8.48**	**< .0001**
	1-4	**-0.047**	**0.006**	**-0.06**	**-0.03**	**-7.94**	**< .0001**
	1-5	**-0.032**	**0.006**	**-0.05**	**-0.02**	**-5.41**	**< .0001**
	2-3	-0.001	0.006	-0.02	0.02	-0.21	1.000
	2-4	0.002	0.006	-0.01	0.02	0.32	0.998
	2-5	**0.017**	**0.006**	**0.00**	**0.03**	**2.86**	**0.035**
	3-4	0.003	0.006	-0.01	0.02	0.53	0.984
	3-5	**0.018**	**0.006**	**0.00**	**0.03**	**3.07**	**0.018**
	4-5	0.015	0.006	0.00	0.03	2.54	0.083

Note. LCL and UCL represent the lower and upper confidence limits, respectively, of the 95% confidence intervals. Significant results are in bold.

Table 9. Contrasts between expressions by congruency of model MC

Model MC							
Congruency	**contrast**	**Estimate**	**SE**	**LCL**	**UCL**	**t ratio**	**p value**
congruent	**anger-fear**	**-0.036**	**0.006**	**-0.05**	**-0.02**	**-5.99**	**< .0001**
	anger-happy	-0.008	0.006	-0.02	0.01	-1.27	0.710
	anger-neutral	**-0.028**	**0.006**	**-0.04**	**-0.01**	**-4.73**	**< .0001**
	anger-sad	-0.014	0.006	-0.03	0.00	-2.39	0.119
	fear-happy	**0.028**	**0.006**	**0.01**	**0.04**	**4.72**	**< .0001**
	fear-neural	0.008	0.006	-0.01	0.02	1.26	0.716
	fear-sad	**0.021**	**0.006**	**0.01**	**0.04**	**3.60**	**0.003**
	happy-neutral	**-0.021**	**0.006**	**-0.04**	**0.00**	**-3.46**	**0.005**
	happy-sad	-0.007	0.006	-0.02	0.01	-1.12	0.799
	neutral-sad	0.014	0.006	0.00	0.03	2.34	0.132
incongruent	**anger-fear**	**-0.018**	**0.006**	**-0.03**	**0.00**	**-2.98**	**0.024**
	anger-happy	-0.009	0.006	-0.03	0.01	-1.53	0.544
	anger-neutral	-0.006	0.006	-0.02	0.01	-0.94	0.881
	anger-sad	-0.006	0.006	-0.02	0.01	-1.08	0.817
	fear-happy	0.009	0.006	-0.01	0.02	1.45	0.592
	fear-neural	0.012	0.006	0.00	0.03	2.04	0.246
	fear-sad	0.011	0.006	0.00	0.03	1.90	0.316
	happy-neutral	0.004	0.006	-0.01	0.02	0.59	0.977
	happy-sad	0.003	0.006	-0.01	0.02	0.45	0.992
	neutral-sad	-0.001	0.006	-0.02	0.02	-0.14	1.000

Note. LCL and UCL represent the lower and upper confidence limits, respectively, of the 95% confidence intervals. Significant results are in bold.

Four-Bin models: MA and MB

Four-bin models were computed following the same protocols as those reported in the manuscript with five-bin models. However, we used four 25% bins (e.g., Ülrich et al., 2015, figure 8). The considerations for fixed effects and random parameter structures were the same as for the five-bin models. Similarly, the reported results were obtained using the same R libraries as those used for the five-bin models.

Model MA compared social vs. non-social, whereas model MB compared face vs. eyes. vs. arrows stimuli (Figure 1).

A) B)

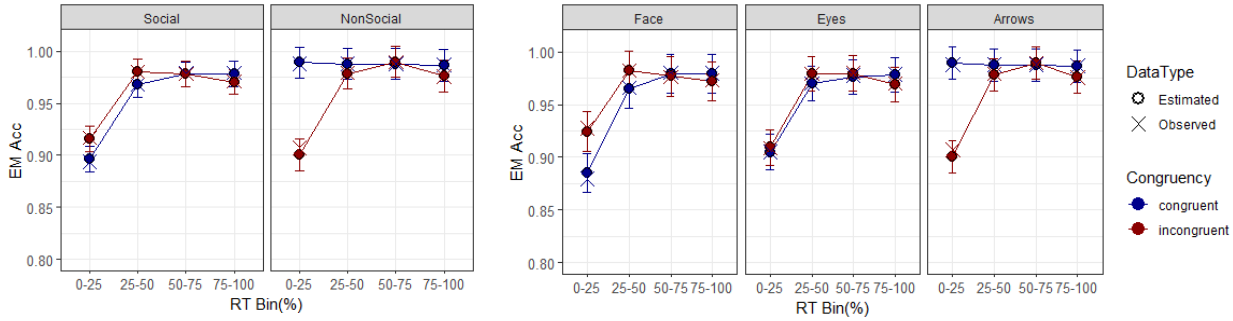


Figure 1. A) CAF for four bin model MA. B) CAF for four bin model MB. The y-axis represents the estimated marginal means of accuracy rate (EM Acc). The bars represent the 95% confidence intervals of the EM Acc. Observed values are represented by 'X' and estimated values by 'O'.

In model MA, the differences between congruent and incongruent trials were noted in Bin 1, with lower accuracy rates for congruent trials in social stimuli, while lower accuracy rates in incongruent trials were noted for non-social stimuli. In model MB, the difference with eyes, although following the same trend as previously observed, was not significant ($p = 0.660$). In contrast, for faces, and arrows, the differences persisted in the same direction as in the model with 5 bins.

Table 10. Contrasts of congruency (congruent vs. incongruent) by Bin and target type of the four bins models

Model MA							
Target Type	**Bin**	**Estimate**	**SE**	**LCL**	**UCL**	**t ratio**	**p value**
Social	**1**	**-0.020**	**0.007**	**-0.03**	**-0.01**	**-2.84**	**0.005**
	2	-0.013	0.007	-0.03	0.00	-1.82	0.071
	3	-0.001	0.007	-0.01	0.01	-0.08	0.937
	4	0.008	0.007	-0.01	0.02	1.11	0.267
Non-social	**1**	**0.088**	**0.009**	**0.07**	**0.11**	**10.12**	**< .0001**
	2	0.009	0.009	-0.01	0.03	1.05	0.293
	3	-0.002	0.009	-0.02	0.02	-0.24	0.811
	4	0.010	0.009	-0.01	0.03	1.17	0.242
Model MB							
Target Type	**Bin**	**Estimate**	**SE**	**LCL**	**UCL**	**t ratio**	**p value**
Face	**1**	**-0.040**	**0.011**	**-0.06**	**-0.02**	**-3.73**	**< .001**
	2	-0.017	0.011	-0.04	0.00	-1.60	0.113
	3	0.003	0.011	-0.02	0.02	0.26	0.793
	4	0.007	0.011	-0.01	0.03	0.62	0.536
Eyes	1	-0.004	0.010	-0.02	0.01	-0.44	0.660
	2	-0.009	0.010	-0.03	0.01	-0.98	0.330
	3	-0.003	0.010	-0.02	0.02	-0.34	0.734

	4	0.009	0.010	-0.01	0.03	0.93	0.356
Arrows	**1**	**0.088**	**0.009**	**0.07**	**0.11**	**9.97**	**< .0001**
	2	0.009	0.009	-0.01	0.03	1.04	0.301
	3	-0.002	0.009	-0.02	0.02	-0.24	0.814
	4	0.010	0.009	-0.01	0.03	1.16	0.247

Note. LCL and UCL represent the lower and upper confidence limits, respectively, of the 95% confidence intervals. Significant results are in bold.

The contrasts between Bins across congruency levels showed similar patterns to those observed with five-bin models. In model MA, social targets exhibited a significant reduction in accuracy in bin 1 compared to the other bins in both congruent and incongruent trials, whereas non-social targets showed a reduction in accuracy only in incongruent trials. Similarly, in model MB, both congruency levels showed reduced accuracy in the first bin compared to the rest with face and eye stimuli, whereas arrows showed a reduction only in incongruent trials.

Table 11. Contrasts of Bin by target type and congruency of the four bins models

Model MA

Target Type - congruency	**Bin Contrast**	**Estimate**	**SE**	**LCL**	**UCL**	**t ratio**	**p value**
Social – congruent	**1-2**	**-0.071**	**0.007**	**-0.09**	**-0.05**	**-10.16**	**< .0001**
	1-3	**-0.082**	**0.007**	**-0.10**	**-0.06**	**-11.60**	**< .0001**
	1-4	**-0.082**	**0.007**	**-0.10**	**-0.06**	**-11.69**	**< .0001**
	2-3	-0.010	0.007	-0.03	0.01	-1.44	0.475
	2-4	-0.011	0.007	-0.03	0.01	-1.52	0.425
	3-4	-0.001	0.007	-0.02	0.02	-0.08	1.000
Social – incongruent	**1-2**	**-0.064**	**0.007**	**-0.08**	**-0.05**	**-9.14**	**< .0001**
	1-3	**-0.062**	**0.007**	**-0.08**	**-0.04**	**-8.84**	**< .0001**
	1-4	**-0.054**	**0.007**	**-0.07**	**-0.04**	**-7.73**	**< .0001**
	2-3	0.002	0.007	-0.02	0.02	0.29	0.991
	2-4	0.010	0.007	-0.01	0.03	1.41	0.497
	3-4	0.008	0.007	-0.01	0.03	1.11	0.682
Non-social - congruent	1-2	0.001	0.009	-0.02	0.02	0.15	0.999
	1-3	0.001	0.009	-0.02	0.02	0.14	0.999
	1-4	0.003	0.009	-0.02	0.03	0.30	0.990
	2-3	0.000	0.009	-0.02	0.02	-0.01	1.000
	2-4	0.001	0.009	-0.02	0.02	0.15	0.999
	3-4	0.001	0.009	-0.02	0.02	0.16	0.999
Non-social - incongruent	**1-2**	**-0.078**	**0.009**	**-0.10**	**-0.06**	**-8.92**	**< .0001**
	1-3	**-0.089**	**0.009**	**-0.11**	**-0.07**	**-10.22**	**< .0001**
	1-4	**-0.075**	**0.009**	**-0.10**	**-0.05**	**-8.65**	**< .0001**

	2-3	-0.011	0.009	-0.03	0.01	-1.30	0.562
	2-4	0.002	0.009	-0.02	0.03	0.27	0.993
	3-4	0.014	0.009	-0.01	0.04	1.57	0.398

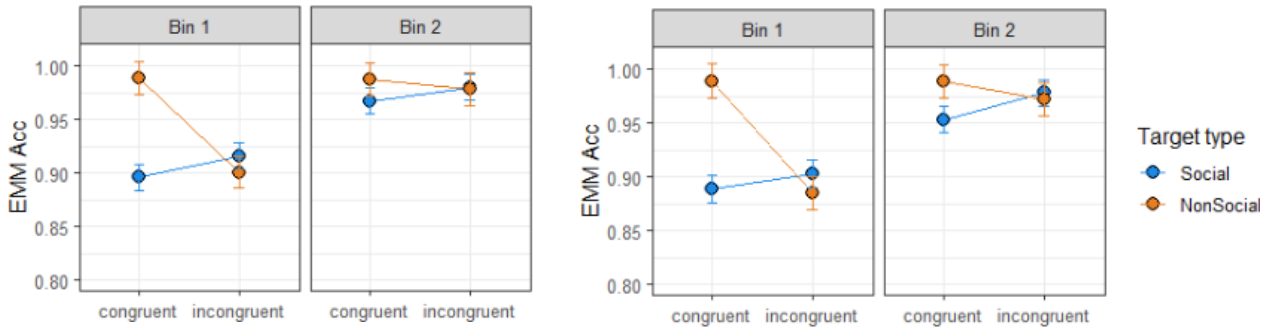
Model MB

Target Type - congruency	**Bin Contrast**	**Estimate**	**SE**	**LCL**	**UCL**	**t ratio**	**p value**
Face / congruent	**1-2**	**-0.080**	**0.011**	**-0.11**	**-0.05**	**-7.54**	**< .0001**
	1-3	**-0.095**	**0.011**	**-0.12**	**-0.07**	**-8.90**	**< .0001**
	1-4	**-0.094**	**0.011**	**-0.12**	**-0.07**	**-8.84**	**< .0001**
	2-3	-0.014	0.011	-0.04	0.01	-1.36	0.527
	2-4	-0.014	0.011	-0.04	0.01	-1.30	0.563
	3-4	0.001	0.011	-0.03	0.03	0.06	1.000
Face / incongruent	**1-2**	**-0.058**	**0.011**	**-0.09**	**-0.03**	**-5.41**	**< .0001**
	1-3	**-0.052**	**0.011**	**-0.08**	**-0.02**	**-4.91**	**< .0001**
	1-4	**-0.048**	**0.011**	**-0.08**	**-0.02**	**-4.50**	**< .0001**
	2-3	0.005	0.011	-0.02	0.03	0.50	0.959
	2-4	0.010	0.011	-0.02	0.04	0.91	0.797
	3-4	0.004	0.011	-0.02	0.03	0.41	0.976
Eyes / congruent	**1-2**	**-0.065**	**0.010**	**-0.09**	**-0.04**	**-6.73**	**< .0001**
	1-3	**-0.071**	**0.010**	**-0.10**	**-0.05**	**-7.43**	**< .0001**
	1-4	**-0.073**	**0.010**	**-0.10**	**-0.05**	**-7.59**	**< .0001**
	2-3	-0.007	0.010	-0.03	0.02	-0.70	0.898
	2-4	-0.008	0.010	-0.03	0.02	-0.86	0.828
	3-4	-0.002	0.010	-0.03	0.02	-0.16	0.999
Eyes / incongruent	**1-2**	**-0.070**	**0.010**	**-0.09**	**-0.04**	**-7.27**	**< .0001**
	1-3	**-0.070**	**0.010**	**-0.10**	**-0.05**	**-7.33**	**< .0001**
	1-4	**-0.060**	**0.010**	**-0.08**	**-0.03**	**-6.22**	**< .0001**
	2-3	-0.001	0.010	-0.03	0.02	-0.06	1.000
	2-4	0.010	0.010	-0.01	0.03	1.05	0.722
	3-4	0.011	0.010	-0.01	0.04	1.11	0.686
Arrows – congruent	1-2	0.001	0.009	-0.02	0.02	0.15	0.999
	1-3	0.001	0.009	-0.02	0.02	0.14	0.999
	1-4	0.003	0.009	-0.02	0.03	0.29	0.991
	2-3	0.000	0.009	-0.02	0.02	-0.01	1.000
	2-4	0.001	0.009	-0.02	0.02	0.15	0.999
	3-4	0.001	0.009	-0.02	0.02	0.16	0.999
Arrows – incongruent	**1-2**	**-0.078**	**0.009**	**-0.10**	**-0.05**	**-8.79**	**< .0001**
	1-3	**-0.089**	**0.009**	**-0.11**	**-0.07**	**-10.07**	**< .0001**
	1-4	**-0.075**	**0.009**	**-0.10**	**-0.05**	**-8.51**	**< .0001**
	2-3	-0.011	0.009	-0.03	0.01	-1.28	0.576
	2-4	0.002	0.009	-0.02	0.03	0.27	0.993
	3-4	0.014	0.009	-0.01	0.04	1.55	0.409

Note. LCL and UCL represent the lower and upper confidence limits, respectively, of the 95% confidence intervals. Significant results are in bold. Significant results are in bold.

Overall, the interaction plot (Figure 2) revealed that the patterns align with reported trends across five bins, especially concerning the differences between stimulus types. Even though the dissociation with eye stimuli did not reach significance, there is a clear distinction when compared to arrows in the first bin. This change could be explained by the fact that with five bins, the distribution is divided in a more nuanced manner, making the range for faster responses more specific. In contrast, a four-bin CAF might mix information between faster and middle response latencies.

A)



B)

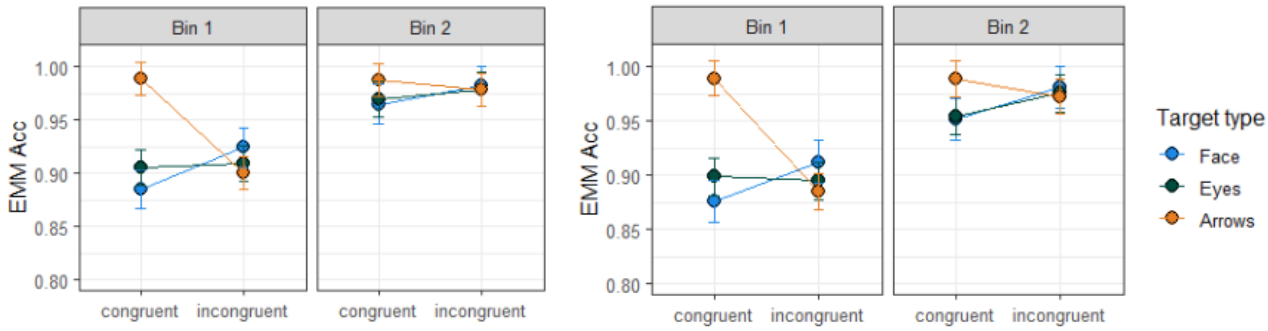


Figure 2. Interaction plot for the first two bins of congruency levels by target type. The left figures display the 4-bin models, while the right figures are the 5-bin models. A) Model MA compares social versus non-social stimuli. B) Model MB compares face, eyes, and arrows stimuli.

Appendix B. Supplemental Materials for Study 2

Trimming procedure

For the trimming procedure, we adopted the cutoff thresholds used in most original studies, discarding reaction times below 200ms and above 1300ms (Table 1). This approach was consistently applied across all studies, including Dalmaso et al. (2023), despite their original use of a 3 standard deviation (SD) trimming method. The analyses included only correct responses.

Table 1. Error rates, remaining trials and trials removed by study

Study	**Remaining trials (%)**	**Incorrect trials (%)**	**Trials trimmed (%)**
Torres-Marín et al. (2017), experiments 1 / 2	94.56% / 95.05%	5.44% / 4.95%	.01% (<*200*), .75% (>*1300*) / .00% (<*200*), .92% (>*1300*)
Marotta et al. (2018)	96.85%	3.15%	.01% (<*200*), .25% (>*1300*)
Marotta & Lupiáñez (2018)	97.97%	2.03%	.00% (<*200*), .38% (>*1300*)
Marotta et al. (2019)	96.79%	3.21%	.00% (<*200*), .38% (>*1300*)
Hemmerich et al. (2022), experiments 1 / 2	97.77% / 95.55%	2.23% / 4.45%	.00% (<*200*), .64% (>*1300*) / .00% (<*200*), .52% (>*1300*)
Narganes-Pineda et al. (2022), experiment 1	97.34%	2.66%	.00% (<*200*), .52% (>*1300*)
Marotta et al. (2022)	94.63%	5.37%	.01% (<*200),* .82% (>*1300*)
Bonventre & Marotta (2023), experiments 1 / 2	97.75% / 96.92%	2.25% / 3.08%	.00% (<*200*), .37% (>*1300*) / .00% (<*200*), .55% (>*1300*)
Ishikawa et al. (2024), experiments 1 / 3	96.01% / 95.86%	3.99% / 4.14%	.12% (<*200*), .65% (>*1300*) / .30% (<*200*), .27% (>*1300*)
Tanaka et al. (2023), experiments 1A / 1B	94.87% / 95.8%	5.13% / 4.20%	.04% (<*200*), .59% (>*1300*) / .00% (<*200*), .09% (>*1300*)
Dalmaso et al. (2023)	97.31%	2.69%	.00% (<*200*), .07% (>*1300*)

Note. For studies with multiple experiments, the reported values are separated by a slash. The column 'Remaining trials' shows the percentage of correct responses left after applying the trimming procedure and removing incorrect trials. The reported incorrect trials were calculated post-trimming. The column 'Trials trimmed' indicates the percentage of correct trials that were faster than 200ms (<200) or slower than 1300ms (>1300).

Additionally, the same analyses were conducted after excluding trials without a response (i.e., employing the non-trimmed dataset). Both the RT and Delta models remained consistent with the overall analysis. In contrast, the Trend model analyses showed consistent patterns for face and eye targets, but significant changes were observed with arrow targets (see Trend analysis section), which are mentioned in the manuscript. The non-trimmed datasets and script are available on the OSF webpage (see Data Availability Statement).

Grouping structure & stepwise analysis results

The best-fitting models were selected using a stepwise approach with the 'step' function from the 'lmerTest' R package (Kuznetsova et al., 2017) on the RT and Delta models. The RT model initially included a three-way interaction between target type, congruency and quantile (QQ), while the Delta model included a two-way interaction between target type and quantile (QQ). Random effects reflected the grouping structure, following Ponce et al. (2024), using crossed effects syntax for implicit nesting (e.g., Schielzeth & Nakagawa, 2013), while also considering strategies to improve model fit (Barr, 2013; Meteyard & Davies, 2020). Participants were nested within studies (1|Studies:id), with target type treated as study-specific (*1|Study:TargetType*). The unique distributional structure of each study was also accounted for: the RT model included congruency and quantile factors (*1|Study:TargetType:Congruency:QQ*), and the Delta model included quantile factor (*1|Study:TargetType:QQ*). This approach allowed for more flexible modeling, capturing both individual and target-type variations within studies, as well as distributional differences within studies.

The stepwise process used backward elimination, sequentially removing effects, starting with random effects and then fixed effects, while adhering to the principle of marginality (McCullagh & Nelder, 1989). P-values for fixed effects are derived from an F-

test using Satterthwaite's approximation, while random effects p-values were calculated using likelihood ratio tests. In the RT model, the three-way interaction was not significant, leading to a simplified model focusing on two-way interactions. The Delta model showed a significant interaction between target type and quantile. In both models, all random grouping structures yielded significant results.

Table 2. Stepwise analyses results

RT model			
Random parameters	**logLik**	**LRT**	**p**
(1:Study:id)	-71 665	9 825.8	< .0001
(1|Study:TargetType)	-66 862	219.3	< .0001
(1|Study:TargetType:Congruency:QQ)	-66 842	180.5	< .0001
Fixed parametersR	**Sum Sq**	**F**	**p**
TargetType * Congruency * QQ	13 477	.63	.7526
TargetType * Congruency	790 414	147.68	< .0001
TargetType * QQ	275 224	12.86	< .0001
Congruency * QQ	45 469	4.25	.0025
Delta model			
Random parameters	**logLik**	**LRT**	**p**
(1:Study:id)	-32 988	855.92	< .0001
(1|Study:TargetType)	-32 579	36.85	< .0001
(1|Study:TargetType:QQ)	-32 565	10.28	.0013
Fixed parameters	**Sum Sq**	**F**	**p**
TargetType * Congruency * QQ	68 580	3.99	.0004

Note. the logLik column represents the likelihood function, the LRT provides the likelihood ratio test estimates, and the Sum Sq shows the sum of squares.

Non-trimmed, quartile and decile models

The delta model fitted with the non-trimmed dataset, as well as the quartile and decile models, followed the same protocols used in the main delta model reported in the manuscript. In all cases, the two-way interaction between target type and quantile was significant, indicating consistent overall patterns.

The quartile model used four data points at probabilities *.2*, *.4*, *.6*, and *.8* (e.g., Castel et al., 2007), employing equally space probabilities (e.g., Tanaka et al., 2025). Additionally, a modified quartile model (quartile-B) was tested at probabilities *.1*, *.3*, *.7* and *.9* to emphasize the tails of the distribution—similar to the approach used in the main delta model (i.e., five quantiles).

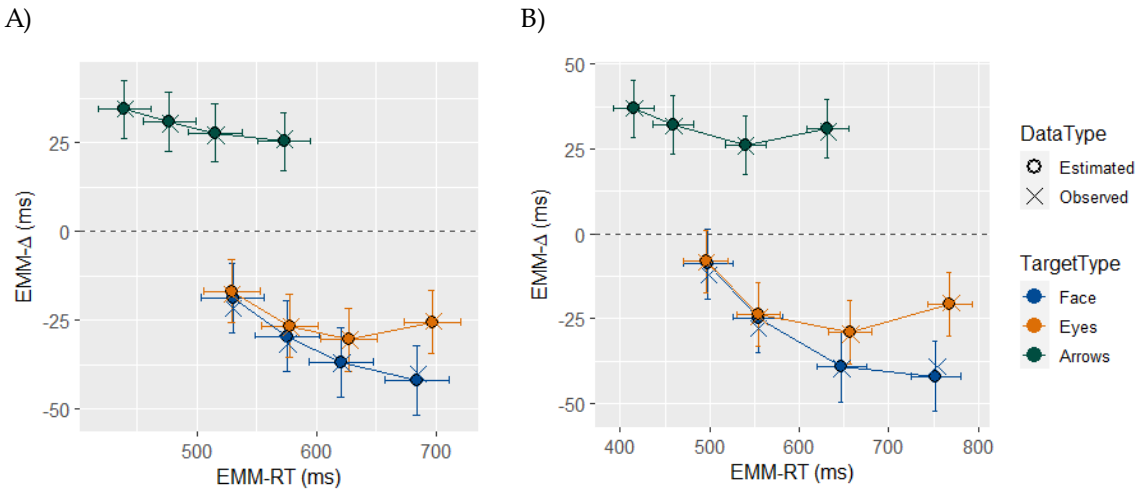


Figure 1. Delta plots of quartile model is shown in A) and its modified version, quartile-B, is shown in B). The y-axis displays the estimated marginal means of the delta function (EMM-Δ), with bars representing the 95% confidence intervals. The x-axis shows the estimated marginal means of reaction time (EMM-RT), with the bars representing the 95% confidence interval for the EMM-RT. Observed values are represented by 'X' and estimated values by 'O'.

The quartile model showed a significant reversion for social stimuli starting from the first quartile (Figure 1A), consistent with Tanaka et al. (2025). In contrast, the quartile-B model showed no significant effect at the first quartile, aligning with the results from the delta and decile models. These findings suggest that the reduction in the conflict effect occurs only within very specific segments of the RT distribution—particularly in the fastest responses (between .05 and .1 proportions). Additionally, the fourth quartile displayed a marginally larger reversion for faces ($p = .0457$), with a significant difference observed in the quartile-B model ($p < .0001$).

The decile model employed ten data points (e.g., Pratte et al., 2021), at probabilities *.05, .15, .25, .35, .45, .55, .65, .75, .85, and .95* (Figure 2).

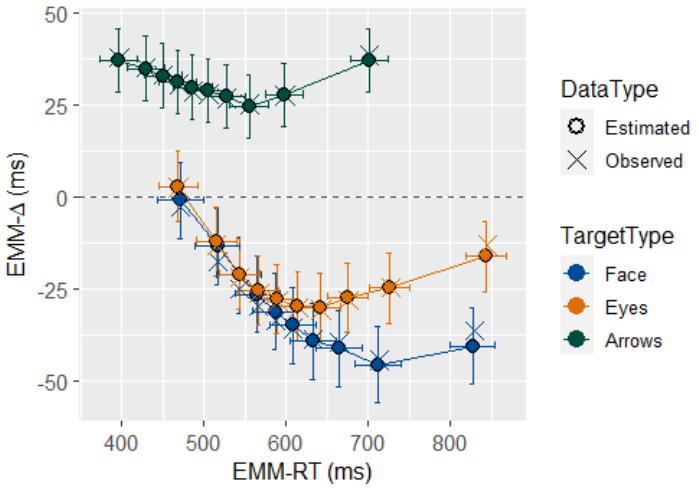


Figure 2. Delta plots derived from the decile model. The y-axis displays the estimated marginal means of the delta function (EMM-Δ), with bars representing the 95% confidence intervals. The x-axis shows the estimated marginal means of reaction time (EMM-RT), with the bars representing the 95% confidence interval for the EMM-RT. Observed values are represented by 'X' and estimated values by 'O'.

The reversion with social targets in the decile model was significant from the second decile onward. The first decile showed no significant effect, implying that the conflict effect was minimal at this portion of the distribution. Additionally, faces exhibited a larger RCE at deciles nine ($p = .0114$) and ten ($p = .0029$).

Trend analyses

The Trend model, fitted to the delta dataset, included target type, mean reaction time by quantile, and their interaction. It was designed to assess whether the delta function followed a linear or quadratic trend. Random effects accounted for the grouping structure, similarly to the Delta model, with the formula as follows:

$$delta \sim TargetType * poly(meanRT, degree = 2) + (1 | Study:id) + (1 | Study:TargetType) + (1 | Study:TargetType:meanRT)$$

The results showed stable trends for social targets. In contrast, for non-social stimuli, the findings were sensitive to the trimming procedure and quantile selection.

Table 3. Results of the trend analyses by model and target type

	Linear			Quadratic		
Quantile Trend model						
Target type	**coeff.**	**t ratio**	**p value**	**coeff.**	**t ratio**	**p value**
Face	-.200 [-.23, -.17]	-14.89	< .0001	.0003 [.0002, .0005]	6.92	< .0001
Eyes	-.092 [-.13, -.06]	-6.37	< .0001	.0003 [.0002, .0004]	6.16	< .0001
Arrows	-.007 [-.03, .02]	-0.80	1.00	.0003 [.0002, .0004]	7.04	< .0001
Quartile Trend model						
Face	-.213 [-.25, -.17]	-13.19	< .0001	.0004 [.0002, .0005]	5.83	< .0001
Eyes	-.098 [-.14, -.06]	-5.72	< .0001	.0003 [.0002, .0005]	5.48	< .0001
Arrows	-.048 [-.08, -.02]	-4.32	< .0001	.0003 [.0001, .0004]	4.30	.0001
Decile Trend model						
Face	-.178 [-.20, -.15]	-17.32	< .0001	.0003 [.0002, .0004]	8.62	< .0001
Eyes	-.109 [-.14, -.08]	-9.84	< .0001	.0003 [.0002, .0004]	10.17	< .0001
Arrows	-.015 [-.03, .002]	-2.13	.1005	.0003 [.0002, .0003]	8.23	< .0001
Non-trimmed Trend model						
Face	-.203 [-.24, -.17]	-14.20	< .0001	.0003 [.0002, .0004]	7.13	< .0001
Eyes	-.052 [-.09, -.02]	-3.55	.0012	.0001 [4.4e-06, .0002]	2.52	.0348
Arrows	-.016 [-.04, .01]	-1.60	.3312	.0001 [-4.9e-05, .0002]	1.24	.6434

Note. These analyses were performed using the emtrends functions from the emmeans R package (Lenth, 2023) on the Trend models.

In addition, faces exhibited a significantly more negative linear coefficient than both eyes and arrows across all models assessed. Similarly, eyes showed a more negative slope than arrows in every model except the non-trimmed trend model. in all the models but the non-trimmed trend model. Overall, these results suggest that social stimuli have a more pronounced negative slope than arrows, with faces displaying the steepest negative slope of all.

Appendix C. Supplemental Materials for Study 4

General Aspects

All the results reported in both the main manuscript and the supplemental material were preregistered in Open Science Framework (OSF; see Transparency and Openness section in the manuscript, **Section 3.4.**). Some of the analyses presented here are not directly related to our primary hypotheses but are relevant to additional observations and interpretative points discussed in the main text.

For the analyses most relevant to our primary aims, when no significant effect was observed, we conducted Bayesian tests to quantify the evidence in favor of the null hypotheses (BF_{01}). These analyses were carried out using the BayesFactor package (Morey & Rouder, 2022), applying the default parameters described by Rouder et al. (2009, 2012). Bayes factors (BF_{01}) were interpreted according to the guidelines proposed by Wagenmakers (2007; see table 3).

Extended Analyses

Spatial Stroop Effect

After the trimming procedure described in the manuscript (see the **Method** section), the spatial Stroop effect was calculated for each participant by subtracting the mean reaction time (RT) of correct congruent trials from those of correct incongruent trials. In Experiment 1, we performed paired *t*-tests to compare the size of the congruency effects between target types. In Experiment 2 we first conducted a mixed-design ANOVA with group (within-block vs. between-block) as a between-subjects factor and target type (level-1, level-2, level-3, gaze) as a within-subject factor. This was followed by paired *t*-tests as in Experiment 1. As preregistered, we also compared Stroop effects between groups (see below). Additionally, in both experiments, we performed one-sample *t*-tests against zero to assess whether the observed effects significantly differed from the null hypothesis (i.e., no Stroop effect). **Table 1** presents the mean Stroop effect by experiment and condition.

Table 1.

Mean Spatial Stroop Effect (in milliseconds) by Target Type and Experiment

	Experiment 1	**Experiment2**	
		within	**between**
Arrows (level-1)	22	14	30
	(33.21)	(26)	(35)
Arrows (level-2)	−15	−20	−17
	(35)	(35)	(33)
Arrows (level-3)	−15	−20ms	−19
	(34)	(30)	(31)
Gaze	-	−21	−4
		(40)	(43)

Note. The standard deviations (SD) of the spatial Stroop effect are provided in parentheses.

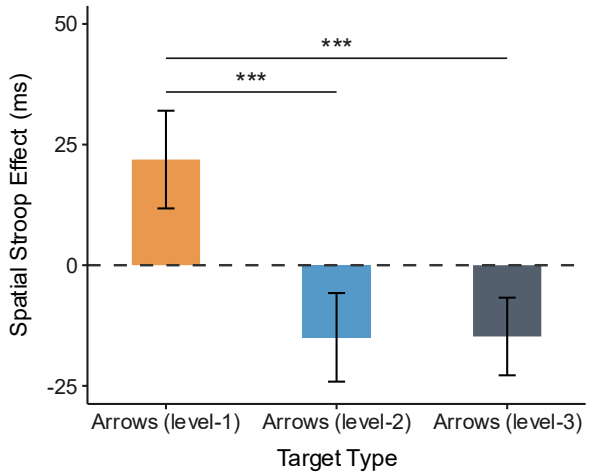
In Experiment 1 (**Figure 1A**), no significant difference was found between level-2 and level-3 arrows. Bayesian paired comparisons provided positive evidence in favor of the null hypotheses (BF_{01} = 5.44), suggesting similar RCE magnitudes for both arrow types. One-sample *t*-tests against zero showed that the conflict effects for all three target types were significantly different from zero.

In Experiment 2 (**Figure 1B**), as reported in the manuscript, the group × target type interaction was not significant. However, both the main effects of group and target type were significant. The within-block group showed a larger reversal than the between-block group. While the SCE for level-1 arrows significantly differed from the RCEs for level-2 arrows, level-3 arrows, as well as gaze targets, no significant differences were found among the three RCE conditions. Bayesian *t*-tests supported the null hypothesis for comparisons between level-2 and level-3 arrows (BF_{01} = 8.37), level-2 and gaze (BF_{01} = 3.54), and to a lesser extent, level-3 and gaze (BF_{01} = 2.83). One-sample *t*-tests confirmed that all congruency effects significantly differed from zero.

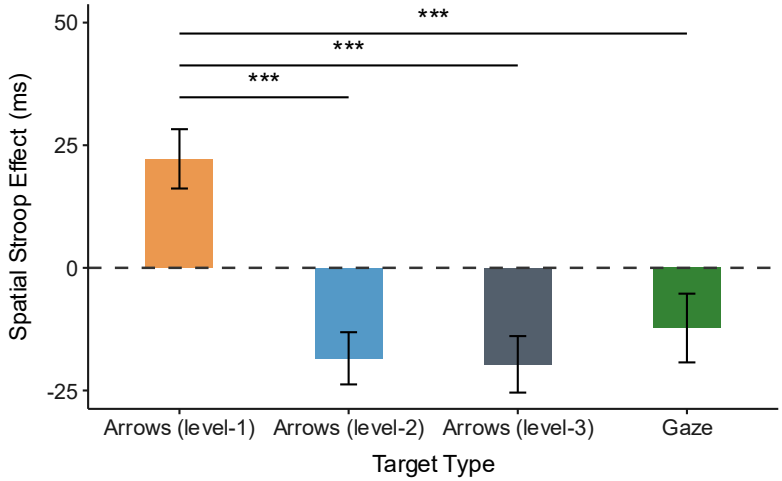
Figure 1

Spatial Stroop Effect by Target Type

A)



B)



Note. Spatial Stroop effect by target type. Panel (A) display the interference effect in Experiment 1 and panel (B) in Experiment 2 (collapsed across groups). Error bars represent 95% confidence intervals, adjusted using the Cousineau–Morey method (Morey, 2008). Asterisks indicate significance levels: *p < .05, **p < .01, *** p < .001.

Although the omnibus interaction between group and target type was not significant, we preregistered specific comparisons to explore whether the Stroop effect would differ between within- and between-block designs. Accordingly, independent samples t-tests were conducted for each target type. These analyses revealed a significant group difference for level-1 arrows, $t(87.05) = -2.57$, $p = .012$, $d_z = -0.53$, and gaze targets, $t(93.27) = -2.01$, $p = .048$, $d_z = -0.41$, although the evidence for the latter was ambiguous

(BF_{01} = 0.80). No significant group differences were found for level-2 or level-3 arrows. Notably, for level-1 arrows, the Stroop effect was larger in the between-block group (30 ms) than in the within-block group (14 ms). Conversely, gaze stimuli elicited a larger RCE in the within-block group (−21 ms) than in the between-block group (−4 ms). Bayesian one sample *t*-tests against zero provided positive evidence for the null only in the between-block group for gaze (BF_{01} = 5.39), suggesting no reliable RCE under blocked presentation.

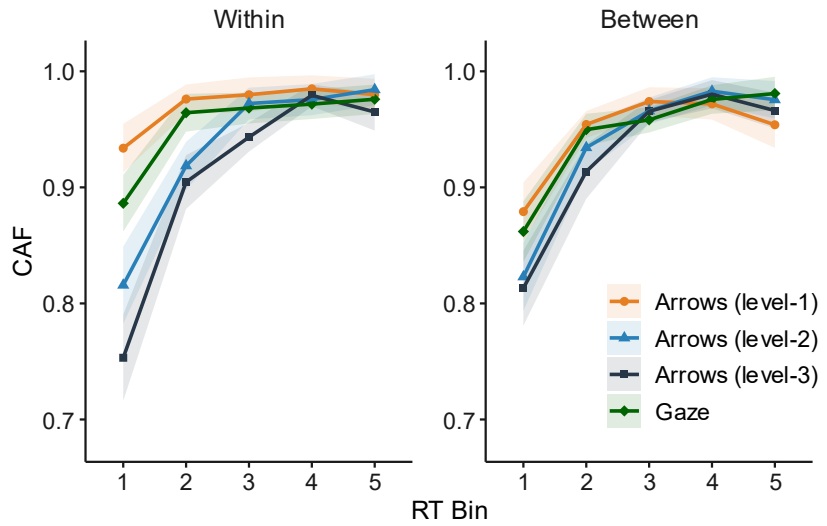
Distributional Analyses

In the general ANOVA on the conditional accuracy function (CAF) data, a significant four-way interaction was observed among group, target type, congruency, and bin (see **Results** section in the manuscript). To unpack this interaction, we conducted follow-up ANOVAs separately for each target type. This strategy allowed us to identify which stimuli contributed most to the interaction by examining whether the Group condition modulated the congruency × bin pattern for each stimulus. Results indicated that this interaction was primarily driven by level-1 arrows, which exhibited a significant three-way interaction, $F(1.87, 175.68) = 7.65$, $p = .001$, $\eta_p^2 = .08$, suggesting that the temporal dynamics of conflict were selectively modulated by group only for this target type.

Additionally, the omnibus interaction revealed a significant three-way interaction between group, target type and bin (**Figure 2**), $F(7.19, 675.93) = 3.51$, $p = .001$, $\eta_p^2 = .04$. Follow up analyses of the first bin revealed that, within the within-block group, level-1 arrows produced the highest accuracy rates, followed by gaze targets, level-2 arrows, and level-3 arrows. In the between-block group, level-1 arrows again yielded higher accuracy than the other non-social targets, though not significantly more than gaze stimuli. Gaze, in turn, showed higher accuracy than level-3 arrows. A similar pattern was observed in the second bin, particularly in the within-block group: accuracy was highest for level-1 arrows, followed by gaze, then level-2, and level-3 arrows. In later bins, accuracy differences among target types diminished in both groups.

Figure 2

CAF by Target Type divided by Group

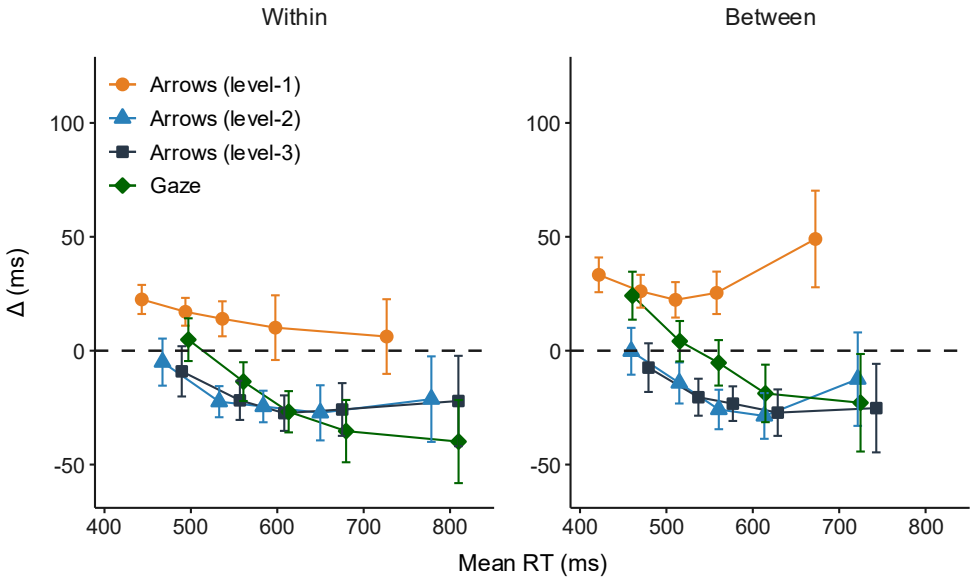


Note. CAF for Experiment 2 by target type and group. Shaded ribbons indicate 95% confidence intervals adjusted using the Cousineau-Morey method (Morey, 2008). The within-block and between-block groups are shown in separate panels.

To further examine how group condition modulated conflict dynamics over time, we compared delta values between groups for each target type across quantiles (**Figure 3**). The results revealed that only level-1 arrows and gaze stimuli exhibited significant group differences. Specifically, for level-1 arrows, the between-block group showed a larger delta value at the first quantile, $t(90.66) = -2.16$, $p = .034$, $d_z = -0.44$, and at the fifth quantile, $t(82.67) = -3.04$, $p = .003$, $d_z = -0.62$. Similarly, for gaze stimuli, significant group differences were found at the first three quantiles ($p < .03$, $d_z < -0.49$), again with stronger effects in the between-block group. No group differences were observed at any quantile for level-2 or level-3 arrows. In this case Bayesian one-sample *t*-test provided positive evidence of the absence of the effect only at the first quantile for gaze in the within-block group ($BF_{01} = 4.67$), whereas in the between-block group there was positive evidence against the null ($BF_{01} = 0.01$), suggesting the facilitation of a SCE.

Figure 3

Delta plots by group for each target type



Note. Delta plots by target type, faceted by group condition in Experiment 2. Error bars represent 95% confidence intervals, adjusted using the Cousineau–Morey method (Morey, 2008).

Critically, although the main interactions did not always reveal a significant role of Group, our preregistered distributional approach provided a more sensitive test of temporal conflict dynamics. By examining accuracy and interference effects across the response time distribution, we found that some differences emerged mainly in the fastest responses. This aligns with previous research recommending distributional methods for analyzing temporal dynamics in conflict tasks (Balota & Yap, 2011, Ellinghaus et al., 2024; Mittelstädt & Miller, 2020; Pratte et al., 2010).

Analyses by Block

The structure of the experiment allowed us to explore whether the strength of the spatial Stroop effect varied across blocks or was influenced by the temporal context in which targets appeared. To assess whether the conflict effect changed over the course of the task in the within-block group, we conducted repeated-measures ANOVA on Stroop interference with block (1-4) and target type as within-subject factors. The critical block × target type interaction was not significant ($F = 1.35$, $p = .230$), indicating that the Stroop interference remained stable across blocks.

In addition, to examine whether the specific block in which Gaze targets were presented affected the Stroop effect, we conducted a mixed-design ANOVA in the between-block group, with target type as a within-subjects factor and gaze block position (i.e., gaze presented in block 1-4) as a between-subjects factor. The interaction between gaze block position and target type was not significant ($F = 1.65$, $p = .108$), suggesting that the order of presentation of gaze stimuli did not influence the Stroop effect.

Appendix D. Pre-Cueing Effects on Spatial Interference

This appendix summarizes preliminary results from an additional line of research conducted during the doctoral period, aimed at investigating how attentional orienting and alerting modulate spatial interference within the broader framework of social attention.

The study extended the integrative account (**Section 1.4.3.**) by examining whether orienting and alertness differentially influence the SCE and the RCE when elicited by arrow and gaze targets. Building on previous findings (Funes et al., 2007; Funes & Lupiáñez, 2003), it tested the prediction that spatial orienting (via peripheral cues) would reduce interference, thereby diminishing the SCE for arrows and enhancing the RCE for gaze, whereas alerting (via auditory warning tones) would increase interference, amplify the SCE and weakening the RCE.

This brief report summarizes two preregistered experiments that shared the same design, differing only in that the second experiment included static placeholders to maintain spatial reference, as is common in orienting paradigms (Chica et al., 2014). The hypothesis, sample size calculations, and design and analysis plans are available in the preregistrations (Experiment 1: https://osf.io/58ybp; Experiment 2: https://osf.io/zpcw7). Only the results that are directly related to our hypothesis are reported below.

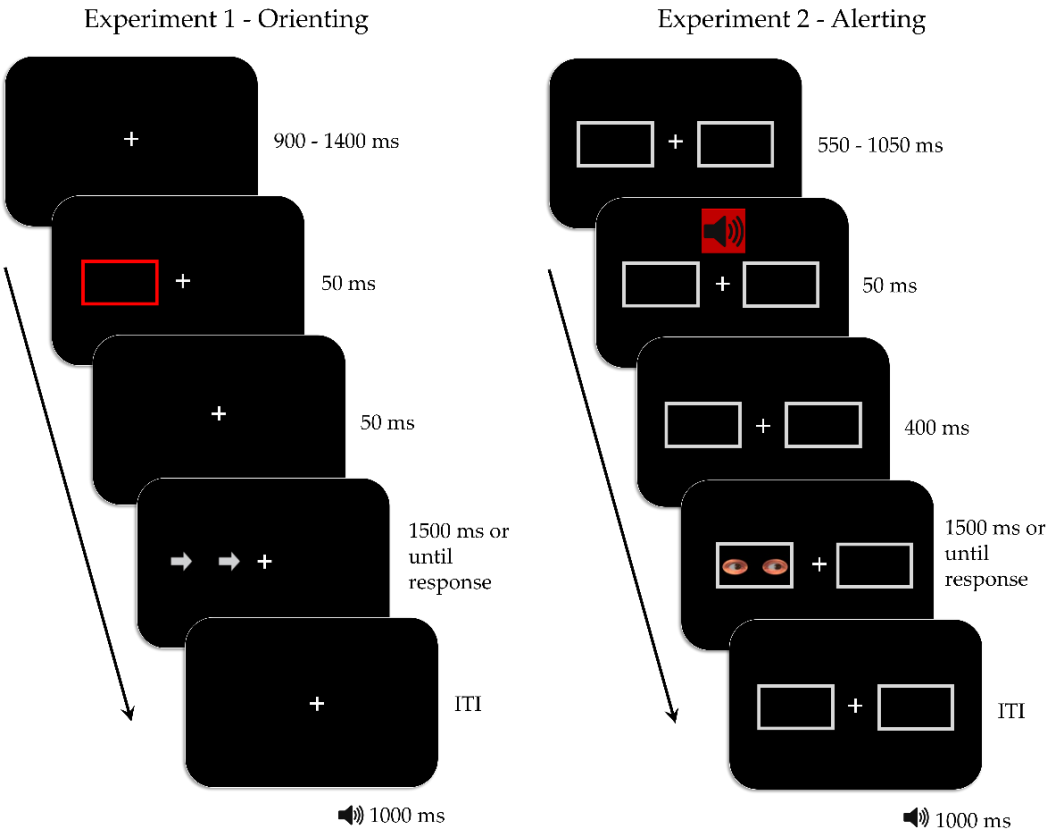
Forty-five students from the University of Granada participated voluntarily in each experiment after giving informed consent. In Experiment 1, the sample included 45 participants (43 female; mean age = 19.4 years, SD = 1.7); in experiment 2, 45 subjects (42 female; mean age = 19.8 years, SD = 1.4). All reported normal or corrected-to-normal vision and were naïve to the study's purpose. Both experiments were conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Granada (Ref. 2442/CEIH/2021).

Stimuli consisted of lateralized arrows and isolated eye-gaze targets pointing left or right. Participants responded as fast and accurate as possible with the *Z* (left) or *M* (right) key to indicate target direction, while ignoring spatial position. Two experimental blocks were performed, depending on the type of pre-cue orienting (red box) and alerting (auditory tone). Each trial began with a fixation cross, followed by the cue, either the red box that validly indicated the target location on 50% of trials on the orienting block, or a

tone presented on 50% of the trials on the alerting block. Feedback was provided only for errors. Each block contained 256 trials (128 per target type). The order of blocks was counterbalanced across participants target types were presented randomly within the same blocks. **Figure D1** illustrates the trial sequence.

Figure D1

Schematic Representation of Trial Sequence



Note. At the left is the trial sequence of the orienting block in Experiment 1, with arrow targets in incongruent trials. At the right is the trial sequence of the alerting block in Experiment2, with gaze targets in incongruent trials. Red sound icon represent the warning sound, while the black sound icon represent the feedback when incorrect responses are produced.

Both experiments employed a within-subject 2 × 2 × 2 factorial design with the following factors: validity/tone (valid vs. invalid/tone vs. no-tone), target type (gaze vs. arrows), and congruency (congruent vs. incongruent).

RTs were submitted to separate ANOVAs for each block. For the RT analyses, responses faster than 200 ms (0.04% in Experiment 1 and 0.56% in Experiment 2) or deviating more than 2.5 SD from the participant's mean (2.90% in Experiment 1 and

3.18% in Experiment 2) were excluded, as well as incorrect responses (4.53 in Experiment 1, and 7.30% in Experiment 2).

The results did not supported our main hypotheses regarding the expected modulations between the SCE and RCE, suggesting no additive effect of the RCE on the SCE. However, some manipulations produced the anticipated effects. In the orienting block, both experiments showed a main effect of validity, with faster responses in valid trials (Exp1. = 515 ms; Exp. 2 = 509 ms) than in invalid trials (Exp. 1 = 569 ms; Exp. 2 = 554 ms). The interaction between target type and congruency was also significant in both experiments: arrows elicited an SCE, whereas gaze produced no effect. The expected validity × congruency interaction emerged only in the second experiment. In both validity conditions, congruent trials were significantly faster than incongruent ones, but the congruency effect was smaller for valid trials (valid = 10ms, invalid = 72ms). Interestingly, an unpredicted triple interaction appeared in the first experiment but not in the second.

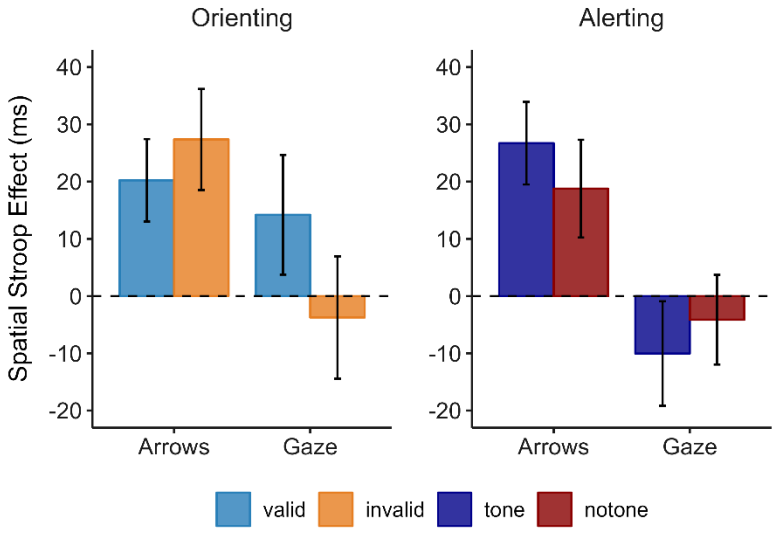
In the alerting block, the expected main effect of tone was observed, with faster responses when the tone was present (Exp. 1 = 517 ms; Exp. 2 = 512 ms), than when it was absent (Exp. 1 = 542 ms; Exp. 2 = 541 ms). Additionally, the target type × congruency interaction was significant in both experiments: arrows produced an SCE, whereas gaze elicited an RCE in the first experiment and no effect in the second. Again, the triple interaction was present in Experiment 1 but not in Experiment 2.

To better visualize the direction and magnitude of these effects, **Figure D2** depicts the spatial Stroop effects for each experiment and condition.

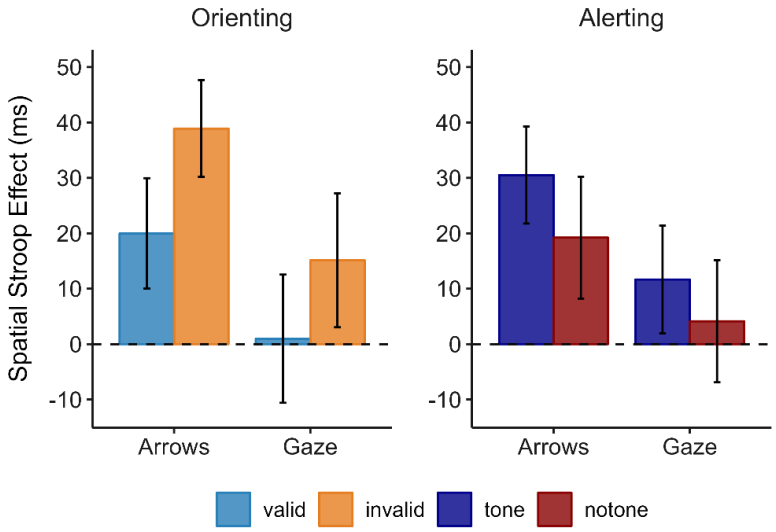
Figure D2

Spatial Stroop Effect by Experiment and Condition

A)



B)



Note. A) Spatial Stroop effect from Experiment 1; B) Saptial Stroop effect from Experimen 2. Experiment 2 included placeholders throughout the task. Error bars indicate 95% confidence intervals computed with the Cousineau–Morey adjustment method (Morey, 2008).

Overall, the results did not reveal a consistent relationship between the SCE and RCE. Nonetheless, they suggest that orienting and alerting mechanisms may interact in specific and non-additive ways. Moreover, the differences between experiments point to a possible modulation by the presence of placeholders, as observed in previous studies (e.g., C. Luo et al., 2013). Accordingly, an additional study was conducted within the doctoral period to test this factor by including the presence and absence of placeholders

as an experimental condition. Given the scope of the present thesis, detailed analyses of this experiment will be reported separately. The preregistration and associated materials are available at https://osf.io/j3ytz.

Appendix E. Reanalysis of Narganes-Pineda, Chica, et al. (2023), Experiment 3A

To examine the distributional dynamic with verbal responses, we reanalyzed data from Narganes-Pineda, Chica, et al. (2023). Specifically, the experiment 3A, which employed a spatial Stroop task with explicit verbal responses. Participants were required to report aloud the direction indicated by arrow or gaze targets presented either congruently or incongruently with their spatial location. Despite the use of verbal responses to explicitly discriminate the direction of arrows or gaze, a SCE was observed for arrows and a RCE for gaze.

The dataset was reanalyzed employing the same approach as in **Study 3-4.** Data were cleaned as in the original study: trials with failed microphone capture were removed, and responses faster than 200 ms or slower than 1300 ms were excluded. CAFs were computed by sorting RTs from fastest to slowest and binning them into five equal-sized bins (20% each). Delta values were obtained via quantile averaging: correct RTs were sorted, and quantile at .1, .3, .5, .7, and .9 probabilities were extracted using R's quantile function with the type 8 estimator. In both cases we followed the same prior procedures.

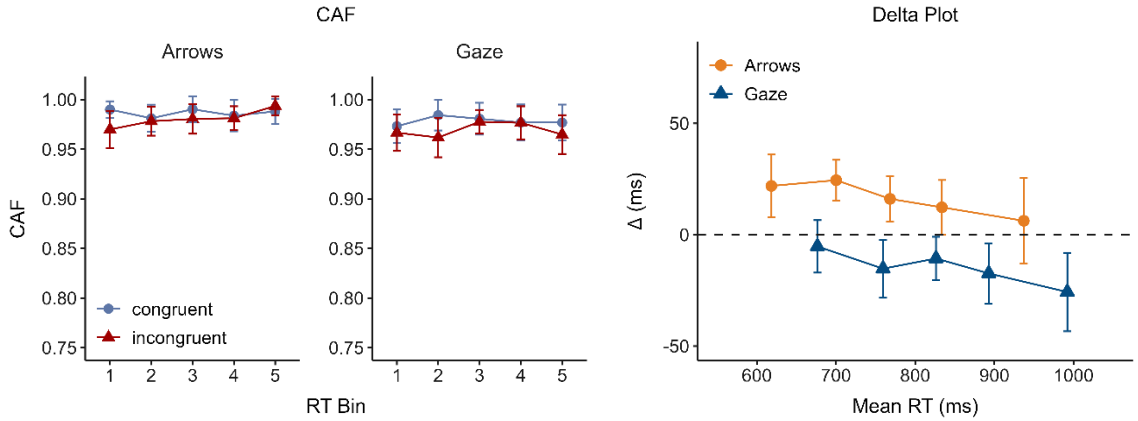
CAF was analyzed in a 2 × 2 × 5 design (target type, congruency and bin); delta function used a 2 × 5 design (target type × quantile). We ran ANOVAs (with Greenhouse-Geisser corrections when appropriate) to test for interactions. For delta values, one-sample *t* tests with Bonferroni adjustment assessed whether conflict effects (incongruent – congruent) differed from zero and their direction. This supplementary analysis is not central to the thesis aims; it supports specific interpretations.

The CAF analysis (**Figure E1, left**) showed a main effect of target type, $F(1, 24) = 9.06$, $p = .006$, $\eta_p^2 = .27$, and congruency, $F(1, 24) = 4.47$, $p = .045$, $\eta_p^2 = .16$, consistent with the original report. The target type × congruency × bin interaction was not significant, $F(4, 96) = 0.90$, $p = .467$, $\eta_p^2 = .04$, indicating no CAF dissociation across bins. The delta function analysis (**Figure E1, right**) revealed a main effect of target type, $F(1, 24) = 19.82$, $p < .001$, $\eta_p^2 = .45$, but no target type × quantile interaction, $F(3.04, 72.87) = 0.61$, $p = .612$, $\eta_p^2 = .03$, reflecting the usual dissociation without distributional modulation. One sample *t* tests showed that arrows elicited an SCE at the first, second, and third quantiles, whereas gaze

showed an RCE at the second, fourth, and fifth quantiles; the remaining quantiles did not differ from zero.

Figure E1

Distributional Analyses from Experiment 3A in Narganes-Pineda, Chica, et al. (2023)



Note. Left: CAFs by target type across bins. Right: Delta plots by target type across quantiles.

Building on the original evidence for reversal with verbal responses, our analysis shows the RCE persists in the distribution, even if CAFs profile changed. Thus, manual responses are not required, but they may modulate the dissociation. This aspect should be tested in future research.

Appendix F. Congruency Effects During the Initial Trials

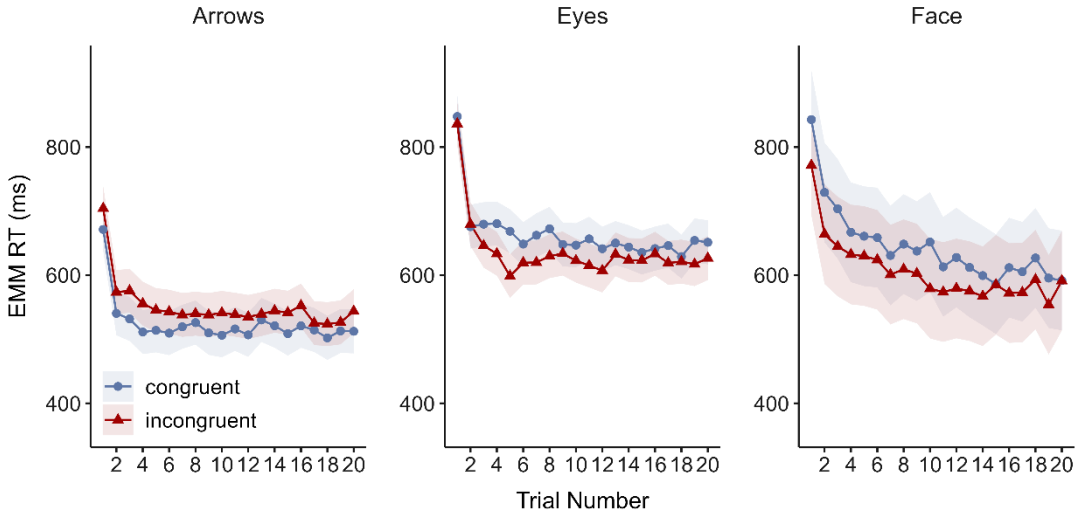
To examine whether reversal dynamics may be present from the very beginning of the task, we conducted an exploratory examination restricted to the first 20 trials of each experiment, including practice trials. For each participant, we selected the first 20 correct responses in the congruent and incongruent conditions, separately for each target type.

This analysis was performed on a pooled dataset drawn from six studies that made their trial-level data publicly available: Marotta et al. (2018; N = 35), Hemmerich et al. (2022; Exp. 1, N = 35; Exp. 2, N = *33*), Narganes-Pineda, Chica, et al. (2023; Exp. 1, N = 24), Bonventre & Marotta (2023; Exp. 1, N = 24; Exp. 2, N = 22), and Tanaka et al. (2023; Exp. 1A, N = 39; Exp. 1B, N = 19). Frome these datasets, we select only arrows, isolates eyes, and upright neutral faces. For Narganes-Pineda, Chica, et al. (2023), we included the explicit task dataset. The data was not trimmed to avoid further loss of early trials.

To describe mean RTs with confidence intervals across the first 20 trials, we modeled the data using LMMs via *lme4* R package (Bates et al., 2015). This approach accounts for the hierarchical structure of the dataset, with participants nested within studies. Specifically, RTs were modeled as a function of target type, congruency, and trial number, with random intercepts for participants nested in studies. Estimated marginal means (EMMs) and 95% confidence intervals were then derived using the *emmeans* package (Lenth et al., 2025), allowing us to visualize the trajectory of congruency and reversal dynamics across the earliest trials (**Figure F1**).

Figure F1

Congruency Effects Across the First 20 Trials by Target Type



Note. EMMs of RTs with 95% confidence intervals across the first 20 valid trials, separated by target type and congruency. Because incorrect responses were removed, the first valid trial for a participant may not correspond exactly to their first exposure. These results are therefore exploratory and descriptive, and the confidence intervals should be interpreted as an illustration of variability rather than as confirmatory statistical evidence.

Although these analyses were not part of the main objectives and should therefore be interpreted cautiously, they provide a useful check on whether reversal dynamics tend to appear from the very outset of task performance. Across datasets, a tendency toward the RCE was already observable within the initial trials.