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

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Abstract

From early ages, gaze acts as a cue to infer the interests, behaviours, thoughts and emotions of social partners. Despite sharing attentional properties with other non-social directional stimuli, such as arrows, gaze produces unique effects. A spatial interference task revealed this dissociation. The direction of arrows was identified faster on congruent than on incongruent direction-location trials. Conversely, gaze produced a reversed congruency effect (RCE), with faster identifications on incongruent than congruent trials. To determine the emergence of these gaze-specific attentional mechanisms, 214 Spanish children (4–17 years) divided into 6 age groups, performed the aforementioned task across three experiments. Results showed stimulus-specific developmental trajectories. Whereas the standard effect of arrows was unaffected by age, gaze shifted from an arrow-like effect at age 4 to a gaze-specific RCE at age 12. The orienting mechanisms shared by gaze and arrows are already present in 4-year olds and, throughout childhood, gaze becomes a special social cue with additional attentional properties. Besides orienting attention to a direction, as arrows would do, gaze might orient attention towards a specific object that would be attentionally selected. Such additional components may not fully develop until adolescence. Understanding gaze-specific attentional mechanisms may be crucial for children with atypical socio-cognitive development.

KEYWORDS
attentional orienting, development, gaze following, social attention, socio-cognitive development, spatial congruency effect

INTRODUCTION

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

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

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

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

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

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

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

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

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

EXPERIMENT 1

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

Method

Participants

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

TABLE 1 Sample descriptives in Experiments 1 and 2

Grade	*N*	Mean (*SD*) age in years	Male	Female
2º grade of infant school	22	4.2 (0.43)	9	13
3º grade of infant school	24	5.3 (0.48)	14	10
1º grade of primary school	27	6.2 (0.42)	15	12
5º grade of primary school	25	10.5 (0.51)	10	15
1º grade of secondary school	60	12.5 (0.50)	31	29

Note: School grades correspond to the Spanish educational system.

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

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

Apparatus and stimuli

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

Since the RCE has been found with both isolated eyes and faces (Cañadas & Lupiáñez, 2012; Marotta et al., 2018), we presented full faces to make the task engaging for children. Stimuli comprised two full-colour photographs, one female and one male, looking to the right or left with a neutral emotional expression, and two horizontal black arrows also pointing to the right or the left (see stimulus examples on Figure 1a). Face stimuli were obtained from the Karolinska Directed Emotional Faces (images id AM25NES and AF21NES) (Lundqvist et al., 1998), and eye directions were modified with Adobe Photoshop CS6. The main criteria for selecting these two specific faces for this study was how clearly gaze direction could be detected (i.e. because of the size and shape of the eyes). Both faces and arrows had been previously used in studies with the same paradigm (e.g. Marotta et al. 2021).

Procedure

We closely followed the procedure of preceding studies (Cañadas & Lupiáñez, 2012; Marotta et al., 2018) with some modifications to adapt the task to age-related special requirements. Children were seated approximately 60 cm from the computer screen with the experimenter placed next to them. As in previous

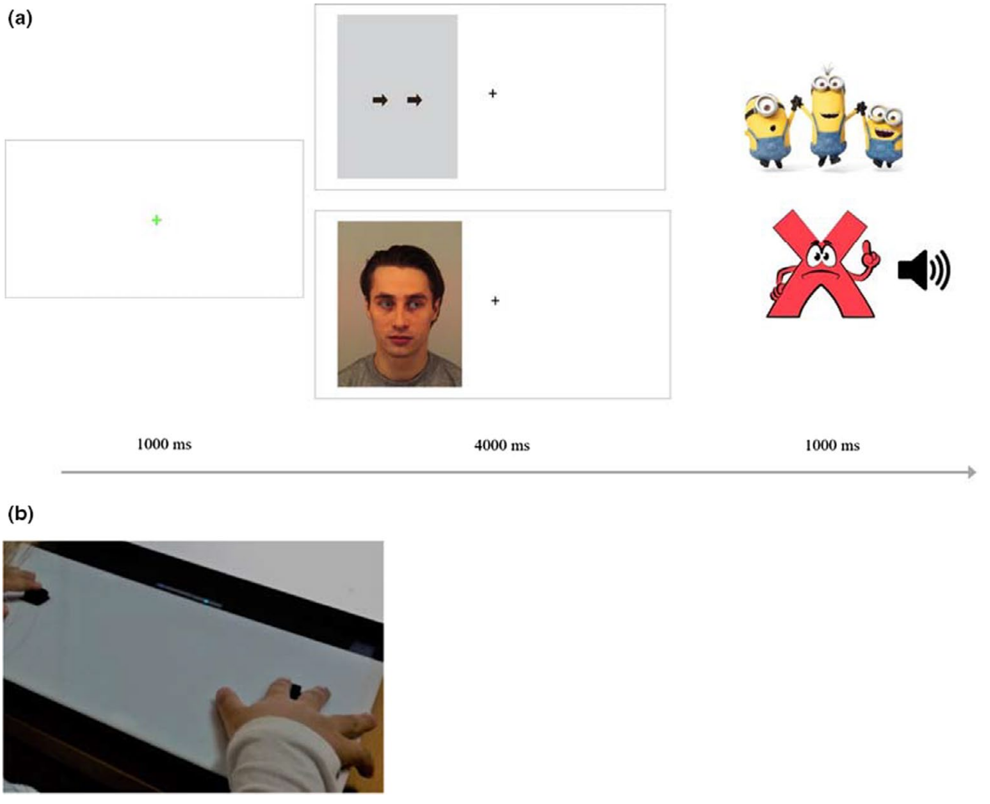

FIGURE 1 Schematic representations of the experimental procedure. *Note*. Panel A: Representation from left to right of the sequence of an incongruent trial of each Target Type. The male face (ID: AM25NES) was obtained from Karolinska Directed Emotional Faces (Lundwvist et al., 1998). Minions cartoons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

studies, they had to discriminate, as fast and accurately as possible, to which direction (right or left) faces or arrows were looking at or pointing to by pressing either the left or the right key on the keyboard ('z' and 'up arrow' respectively) with their corresponding hand. Those keys were selected because they were symmetrically separated on the keyboard of the computer used.

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

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

After practice, children performed 128 trials (64 per target type) divided into 4 identical experimental blocks. During these blocks, only the error feedback was provided to make the task as efficient as possible. However, a display with a randomly appearing cartoon character and the pleasant sound was presented every 16 trials. These pauses, especially in the youngest children, proved to be essential to encourage them to continue by seeking to see the remaining characters and to rest for as long as the experimenter considered necessary. Since the feedback was age adjusted, it had to be slightly changed for the 10-year-old group. Cartoons might be too childish for the older participants, leading to a lack of motivation or rejection of the task. To prevent that, a simple sketch of a hand making an 'okay' gesture replaced cartoon characters. Besides, they had pauses every 32 instead of 16 trials.

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

Design

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

Results

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

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

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

The ANOVA performed on mean RTs revealed a main effect of Age ($F(3, 94) = 88.33$, $p < .001$, $\eta_p^2 = .74$). A post-hoc Bonferroni test showed significant differences between all groups, proving that

TABLE 2 Mean RTs in ms and percentage of error of the five age groups as a function of congruency for each target type in Experiment 1

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

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

children became progressively faster as age increased (1501, 1253, 1045 and 724 ms of overall RT arranged in ascending order of age), with large differences between groups.

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

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

Proportional reaction time

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

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

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

Proportional error rates

For proportional error rate, the ANOVA revealed a main effect of Congruency ($F(1,94) = 76.15$, $p < .001$, $\eta_p^2 = .45$). Children committed fewer errors on congruent than on incongruent trials. No other main

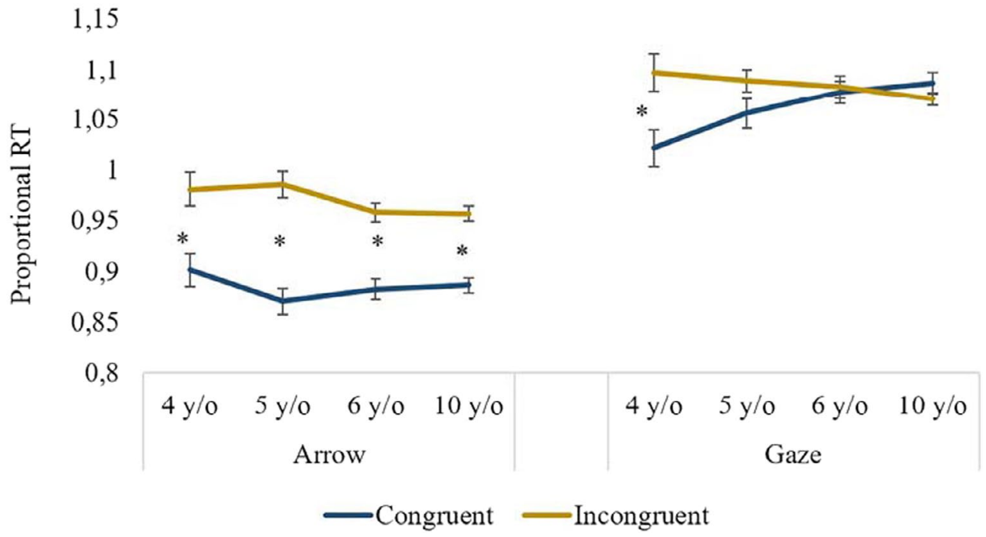

FIGURE 2 Proportional Reaction Time (RT) as a Function of Congruency for Each Target Type and Age Groups in Experiment 1. *Note.* A proportional RT equal to 1 represent the average RT. Values above or below this number would indicate faster or slower responses, respectively, related to the average. Asterisks (*) represent a significant difference between congruency condition (p < .05) obtained from repeated measures ANOVA. Errors bars represent the standard error of the mean

effects were found. However, the Target Type x Age interaction was significant (F(3, 94) = 5.06, p = .003, η_p^2 = .14), finding that while 5-year-old children had a higher error rate responding to arrows than to gaze, the opposite pattern was found in the oldest group. None of these differences were found in the two remaining groups. Congruency by Target type interaction was likewise statistically significant (F(1, 94) = 4.69, p = .033, η_p^2 = .05), showing that arrows had a larger congruency effect than gaze, both in the standard direction. Neither the Age x Congruency interaction (F(3, 94) < 1), nor the three-way interaction of Age, Congruency and Target Type (F(3, 94) < 1) were significant.

Discussion

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

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

EXPERIMENT 2

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

Method

Participants

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

Procedure

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

Results

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

Proportional reaction time

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

It is worth noting that Experiment 2 had a larger sample size than any of the groups of Experiment 1. To verify whether data would be reproduced with a similar number of participants as in Experiment 1, we performed an additional bootstrapping analysis using R Statistical Software (R Core Team, 2021). We used bootstrapping (100 iterations) to randomly select smaller subsamples of 25 participants with replacement from the full sample of 60 (see Bernoster et al., 2019 for a similar example of bootstrapping analysis). This specific number of participants were selected for being the average sample size of the four groups of Experiment 1. Bootstrapping yields an overview of the number of significant results

TABLE 3 Mean RTs in ms and percentage of error as a function of congruency for each target type in Experiment 2

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

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

(based on a significant level of 5%) that would have been obtained with smaller samples across 100 iterations. Data showed 95% of significant Congruency × Gaze interaction and 44% of significant gaze's RCE. Additionally, based on a binomial likelihood function, we estimated the probability of finding those percentages of significant results (out of 100 iterations) given H1 or H0 were true (Lakens & Etz, 2017). Assuming an $\alpha = .05$ and $1\text{-}\beta = .80$, we obtained a likelihood ratio of 1.22×10^{15}, which indicates that our 44% of significant results is 1.22×10^{15} times more likely when H_1 is true than when H_0 is true. This analysis shows that similar results would have been observed in Experiment 2 with a sample size similar to that of each group in Experiment 1.

Proportional error rates

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

Discussion

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

In short, the differential effect between arrows and gaze, previously found in the adult population (Cañadas & Lupiáñez, 2012; Marotta et al., 2018), appears for the first time in 12-year olds. Considering the social relevance of gaze from infancy, 12 years of age could be a relatively late age for the RCE to emerge. In this regard, the absence of differences between arrows and gaze displayed by 4-year olds could be even more surprising. The intermixed way in which arrows and gaze were presented might have affected the lack of RCE observed in the youngest children. In the literature with adult populations, the paradigm has been carried out mostly by presenting the two stimuli separated into counterbalanced blocks (Cañadas & Lupiáñez, 2012; Marotta et al., 2018). On each block, participants responded to a single type of stimulus. However, as explained above, the RCE has also been found with a within-block manipulation of the target type, like in Experiments 1 and 2, with both stimuli being randomly presented within the same block of trials (Narganes-Pineda et al., 2020). Although the effect is unaffected by stimulus presentation with adults, besides the effect being larger with the between-block than the within-block manipulation, it has not been tested with children to date. Particularly in groups of younger children, the absence of RCE may be due to task-context effects rather than gaze-related

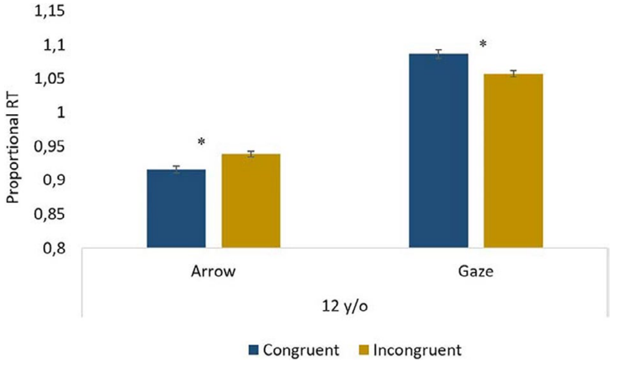

FIGURE 3 Proportional reaction time as a function of congruency for each target type on 12-year olds from Experiment 2. *Note*. A proportional RT equal to 1 represents the average RT. Values above or below this number would indicate faster or slower responses, respectively, related to the average. Asterisks (*) represent a significant difference between congruency condition ($p < .05$) obtained from the repeated measures ANOVA. Errors bars represent standard error of the mean

developmental changes. The youngest children may need a longer exposition to gaze, that is, more consecutive gaze trials, to show the reversion in the congruency effect.

EXPERIMENT 3

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

Method

Participants

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

Procedure

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

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

Design

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

Results

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

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

Proportional reaction time

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

Proportional error rates

The analysis of proportional error rates showed significant main effects of Target Type ($F(1, 53) = 10.71$, $p = .002$, $\eta_p^2 = .17$) and Congruency ($F(1,53) = 44.74$, $p < .001$, $\eta_p^2 = .46$), committing

TABLE 4 Sample descriptives of participants in Experiment 3

Grade	*N*	Mean (*SD*) age in years	Male	Female
2º grade of infant school	15	3.9 (0.26)	9	6
1º grade of primary school	21	6.4 (0.54)	15	6
1º grade of high school	20	17 (0.65)	2	18

Note: School grades correspond to the Spanish educational system.

more errors responding to arrows than to gaze (9.35% vs. 5.70%), and responding to incongruent than congruent trials (10.66% vs. 4.39%). The only significant interaction was Target Type × Congruency ($F(1,53) = 13.55$, $p < .001$, $\eta_p^2 = .20$), being the congruency effect larger for arrows than for gaze.

DISCUSSION

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

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

It should be mentioned that, even though the RCE is clear in adolescents from Experiment 3, they were not age matched to the sample of Experiment 2. Nevertheless, since 12-year olds showed the RCE even with an intermixed presentation of stimuli, they would probably also show it with a blocked one, where the consecutive presentation of the same stimulus would increase effect size (e.g. see Marotta et. al., 2018, for a between-block manipulation, and Narganes-Pineda et. al., 2020, for a within-block one).

GENERAL DISCUSSION

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

In this line, the core aim of our study was to determine how and when additional social components of gaze arise by tracking arrows and gaze differences across age. In particular, we looked for the emergence of the reversed congruency effect (RCE) typically observed with gaze, in contrast to arrows. Results show a completely different developmental path of the congruency effect observed with each stimulus type. The standard congruency effect of arrow remains stable from childhood to early adolescence. Conversely, the effect of gaze changes drastically throughout this period, being indistinguishable from the effect of arrows in 4-year-old children and disappearing from 5 to 10 years of age (Experiment 1). From the age of 5, gaze could progressively gain specific attentional properties that would eventually

TABLE 5 Mean RTs in ms and percentage of error of the three age groups as a function of congruency for each target type in Experiment 3

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

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

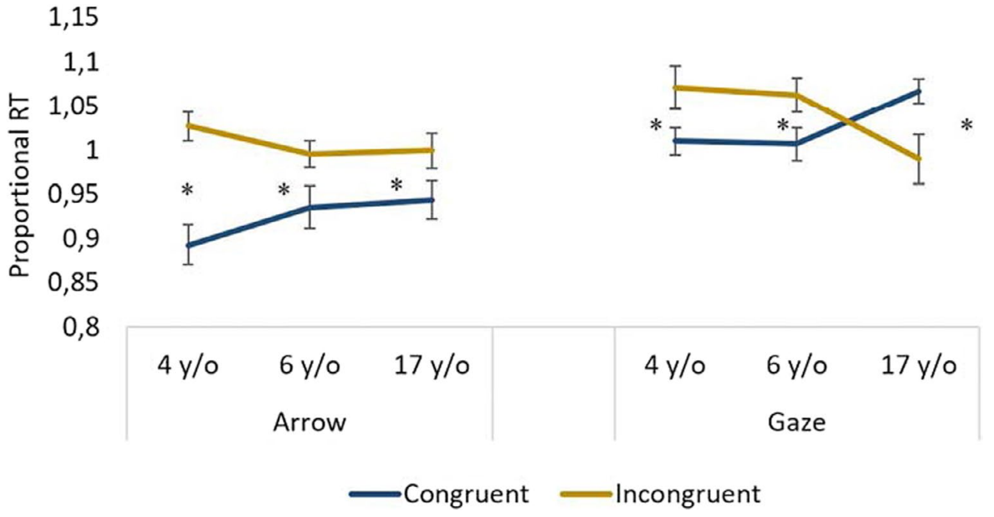

FIGURE 4 Proportional Reaction Time (RT) as a Function of Congruency for Each Target Type Among Age Groups in Experiment 3. *Note.* A proportional RT equal to 1 represents the average RT. Values above or below this number would indicate faster or slower responses, respectively, related to the average. Asterisks (*) represent a significant difference between congruency condition ($p < .05$) obtained from repeated measures ANOVA. Errors bars represent standard error of the mean

lead to a RCE at age 12, as observed in Experiment 2. Furthermore, and importantly, these results are not affected by stimuli presentation since a similar pattern of data was observed both by presenting gaze and arrows randomly on a trial-by-trial basis (Experiment 1 and 2) and by presenting them separated into different blocks of trials (Experiment 3).

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

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

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

Both our results and the suggested explanation fit with the brain developmental course of gaze-related areas, such as the STS. This area, which shows specific activation extracting directional information from goal-directed gaze (Mosconi et al., 2005; Pelphrey et al., 2003, 2005), reaches its maximum cortical thickness between 5 and 11 years of age (Sowell et al., 2004) and, during this period, it also increases activity (Carter & Pelphrey, 2006).

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

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

CONCLUSION

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

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CONFLICT OF INTEREST

None of the authors have any financial interest or conflict of interest.

AUTHOR CONTRIBUTIONS

Juan Lupiáñez (Conceptualization; Formal analysis; Funding acquisition; Methodology; Project administration; Resources; Supervision; Validation; Writing – review & editing) M. Ángeles Ballesteros-Duperón (Conceptualization; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Writing – review & editing) Belén Aranda-Martín, Ph.D student (Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Resources; Visualization; Writing – original draft; Writing – review & editing).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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