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Ignoring Irrelevant Information: Enhanced Intermodal Attention in Synaesthetes

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Abstract

Despite the fact that synaesthetes experience additional percepts during their inducer-concurrent associations that are often unrelated or irrelevant to their daily activities, they appear to be relatively unaffected by this potentially distracting information. This might suggest that synaesthetes are particularly good at ignoring irrelevant perceptual information coming from different sensory modalities. To investigate this hypothesis, the performance of a group of synaesthetes was compared to that of a matched non-synaesthete group in two different conflict tasks aimed at assessing participants' abilities to ignore irrelevant information. In order to match the sensory modality of the task-irrelevant distractors (vision) with participants' synaesthetic attentional filtering experience, we tested only synaesthetes experiencing at least one synaesthesia subtype triggering visual concurrents (e.g., grapheme–colour synaesthesia or sequence–space synaesthesia). Synaesthetes and controls performed a classic flanker task (FT) and a visuo-tactile cross-modal congruency task (CCT) in which they had to attend to tactile targets while ignoring visual distractors. While no differences were observed between synaesthetes and controls in the FT, synaesthetes showed reduced interference by the irrelevant distractors of the CCT. These findings provide the first direct evidence that synaesthetes might be more efficient than non-synaesthetes at dissociating conflicting information from different sensory modalities when the irrelevant modality correlates with their synaesthetic concurrent modality (here vision).

Keywords

Synaesthesia, attention, selective attention, intermodal attention, conflict, visuo-tactile congruency

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1. Introduction

Synaesthesia is a rare, non-pathological condition in which the experience of certain stimuli, known as inducers (e.g., sounds, shapes, or meanings), automatically and involuntarily trigger the perception of additional stimuli, called concurrents (e.g., Ward, 2013). Inducer-concurrent associations are arbitrary and highly specific, and they tend to remain constant over time. For specific groups of synaesthetes, such as sound–colour synaesthetes, who experience automatic colour sensations elicited by sounds or music (e.g., Ward *et al.*, 2006), only the presentation of highly specific perceptual inducers activates synaesthetic concurrents (e.g., Arnold *et al.*, 2012; Witthoft and Winawer, 2006). However, for a large majority of synaesthetes, the experience of the concurrent is triggered by the general concept regardless of the sensory modality which it is internally or externally activated (Chiou and Rich, 2014; Rich *et al.*, 2005; Simner, 2012). That is, for most synaesthetes, concurrents are activated both by thinking about them or by, for example, seeing or hearing its verbal label. For instance, in sequence–space synaesthesia for months (or calendar–form synaesthesia), thinking, hearing, or reading about the months of the year elicits a visuo-spatial representation of this ordinal sequence arranged in specific forms like circles or lines (e.g., Jonas and Price, 2014).

For this reason, the quality of synaesthetic associations has often been compared to that of typical cross-modal correspondences experienced by the general population and links between synaesthesia and multisensory processes have been suggested by different lines of research. For example, similar associations between brightness and pitch (e.g., Ward *et al.*, 2006), colours and textures (e.g., Moos *et al.*, 2013), letters and colours (e.g., Rouw *et al.*, 2014), or sounds and symbolisms (e.g., Milan *et al.*, 2013) have been described for both synaesthetes and non-synaesthetes. Moreover, some researchers have explicitly hypothesised strong overlaps between the brain mechanisms responsible for the integration of information coming from different sensory pathways (i.e., multisensory integration) and synaesthesia (e.g., Bankieris and Simner, 2015; Bien *et al.*, 2012; Simner *et al.*, 2011; Ward *et al.*, 2006). Specific brain areas of the parietal cortex are well known to play a key role in both synaesthetic and non-synaesthetic multisensory integration processes. For example, increased connectivity between parietal and early sensory areas has been observed to facilitate reaction times to audio-visual stimuli, aiding multisensory binding, in typically developed individuals (e.g., Brang *et al.*, 2013). Similarly, integration of synaesthetic associations has been suggested to be mediated by the parietal lobe (either through excessive connections with other brain areas responsible for sensory processing — cross-activation hypothesis, Ramachandran and Hubbard, 2001; or through reduced inhibitory mechanisms — disinhibited-feedback hypothesis, Grossenbacher and Lovelace, 2001). Furthermore, transient disruption of parietal areas has been observed to directly hinder synaesthetes' abilities to experience inducer-concurrent associations (Esterman *et al.*, 2006; Rothen *et al.*, 2010). Taken together, these studies provide initial converging evidence that synaesthesia and multisensory integration might share a common neural substrate.

A defining feature of synaesthesia is the automatic experience of irrelevant percepts elicited by the inducers. Once the triggering stimulus has been processed, the perception of the synaesthetic concurrent is involuntary (e.g., Chiou *et al.*, 2013). This means that synaesthetes frequently and unpredictably experience irrelevant and potentially distracting percepts. For example, number–colour synaesthetes cannot avoid constantly perceiving numbers, which are a common — and, often, random — occurrence in daily life, as specific colours. However, phenomenological reports suggest that many synaesthetes do not consider their inducer-concurrent associations as a source of cognitive interference. For example, in a study conducted by Rich *et al.* (2005) on the implications of grapheme–colour synaesthesia, participant KP illustrated this point reporting that: "It's kind of like looking at your own nose — if you try, you can see it clearly, but you don't walk around the whole time 'seeing' your nose" (see Day, 2005 for other phenomenological testimonies). This observation might indicate that, although synaesthetes cannot avoid experiencing their synaesthetic associations, they are able to ignore the concurrents whenever necessary. Thus, synaesthetes are likely to be particularly effective at rejecting irrelevant information coming from their synaesthetic associations. One interesting question is whether this 'special' filtering ability is extended beyond their specific synaesthetic associations. Or, in other words, do synaesthetes have enhanced filtering or selective attention abilities?

Evidence in this respect is limited. The majority of attention studies on synaesthesia have focussed on the role of attention in synaesthetic perception (see Rich and Mattingley, 2013 for an extensive review on the topic), and not on synaesthetes' general attentional skills. The impact of task-irrelevant information on performance is typically measured in the lab with classic conflict tasks such as the Stroop task (Stroop, 1935), the Eriksen flanker task (Eriksen and Eriksen, 1974), or the Simon task (Simon and Wolf, 1963), providing a measure of participants' attentional abilities. Only a few investigations have directly compared synaesthetes and non-synaesthetes' performance on these tasks, obtaining contrasting results. Van der Veen and colleagues (2014) measured synaesthetes' behavioural and blood-oxygen level dependent (BOLD) responses in the classic Stroop task and observed that they were less sensitive than controls to the interference caused by the task-irrelevant stimuli, suggesting increased attentional abilities. However, other studies have failed to observe behavioural differences between synaesthetes and non-synaesthetes in several classic conflict tasks (Stroop task: Mattingley *et al.*, 2001; 2006; Rouw *et al.*, 2013; flanker task: Rouw *et al.*, 2013).

One possible reason for these conflicting results is that the classic conflict tasks used to assess selective attention in synaesthetes do not engage the same filtering mechanisms that allow synaesthetes to ignore their irrelevant concurrents. If the activation of the synaesthetic concurrent engages multisensory mechanisms, then the attentional filtering of these irrelevant percepts might involve intermodal attention, which is responsible for the filtering of information coming from an irrelevant sensory modality. Importantly, neuroimaging evidence has shown that attention to specific features such as stimulus location and attention to stimuli of specific sensory modalities are mediated by different mechanisms with intermodal attention operating by selective modulation of modality-specific areas (e.g., Eimer and Schröger, 1998; Macaluso *et al.*, 2002; Talsma and Kok, 2002). Thus, rather than general selective attention abilities, synaesthetes might have enhanced intermodal filtering abilities.

Indirect support for the hypothesis that synaesthetes might be better than controls at ignoring an irrelevant sensory modality emerged from recent studies investigating synaesthetes' multisensory integration processes. In two different studies (Neufeld *et al.*, 2012; Sinke *et al.*, 2014), synaesthetes and controls were asked to experience well-established multisensory illusions. Specifically, the Double-Flash Illusion (Shams *et al.*, 2000), which consists of the presentation of a flash accompanied by two beeps creating the false perception of two flashes instead of one; and the McGurk Illusion (McGurk and MacDonald, 1976), which arises when two different visual and auditory semantic stimuli that are shown simultaneously are perceived fuse into a new percept. The illusions occur when incongruent information from different sensory modalities is presented approximately at the same time and from the same location. Stronger multisensory integration typically results in stronger and more frequent illusory perceptions and thus synaesthetes were expected to show stronger susceptibility to the illusions. However, both studies found that synaesthetes experienced fewer double-flash (Neufeld *et al.*, 2012) and McGurk illusions (Sinke *et al.*, 2014) than non-synaesthetes.

Whilst these results might suggest weaker multisensory integration in synaesthetes, reduced rates of illusory perception could also be explained by enhanced intermodal filtering attention abilities. Multisensory integration processes in general (see Koelewijn *et al.*, 2010; Talsma *et al.*, 2010; and Tang *et al.*, 2015 for in-depth reviews), and (at least some) multisensory illusions, are known to be modulated by attention. For example, examination of the early occipito-temporal PD110/PD120 ERPs components showed that the perception of the double-flash illusion was diminished when endogenous spatial attention was directed away from the stimuli (e.g., Mishra *et al.*, 2010). Susceptibility to the same illusion was also reduced when transcranial magnetic stimulation (TMS) was applied to disrupt extrastriate regions involved in selective attention (especially the right cortex) (e.g., Kamke *et al.*, 2012). Even though perceptual illusion tasks have been typically used to measure the strength of multisensory integration (e.g., Stevenson *et al.*, 2014), participants are explicitly instructed to ignore one sensory modality while completely focusing on the other. Hence, it is possible that the reduced illusory susceptibility observed in synaesthetes might have been the consequence of increased intermodal filtering abilities rather than reduced integration capacities (Neufeld *et al.*, 2012).

The aim of the present study was to directly investigate this hypothesis. If synaesthetes are especially efficient at ignoring irrelevant distractors in a different sensory modality, this advantage should be evident in tasks that are typically used to measure intermodal selective attention (i.e., the ability to select a relevant sensory modality over another). To address this issue, we compared the performance of a group of synaesthetes to that of a matched group of non-synaesthetes in the cross-modal congruency task (CCT; Spence *et al.*, 1998), which is a well-known paradigm used to measure multimodal interactions in typically developed individuals as well as clinical populations (e.g., schizophrenia — Stekelenburg *et al.*, 2013; autism spectrum disorder — Foss-Feig *et al.*, 2010; dyslexia — Facoetti *et al.*, 2010; dyspraxia — Bair *et al.*, 2012). In one version of this task (Pavani *et al.*, 2000; Spence *et al.*, 2004), participants are asked to make speeded judgements regarding the elevation of tactile stimuli (i.e., vibration bursts) presented to the index finger (top location) and thumb (bottom location) of either hand, whilst ignoring concurrent visual flashes presented close to the same top–bottom body locations. The visual and tactile stimuli are either shown at the same location (congruent; top flashes –index finger bursts or bottom flashes–thumb bursts) or at different locations (incongruent; top flashes–thumb bursts or bottom flashes–index finger bursts). Responses are faster and more accurate on congruent than incongruent trials giving rise to a consistent congruency effect (CE). Thus, the CE can be considered a measure of the strength of intermodal selective attention abilities: the smaller the CE, the stronger the capacity to filter out irrelevant stimuli in a second sensory modality.

In an attempt to keep the congruency task as close as possible to the type of attentional filtering synaesthetes might naturally experience, we matched the sensory modality of the task-irrelevant distractors in the CCT with the sensory modality of synaesthetes' concurrents. Since the most common forms of synaesthesia involve visual concurrents, only synaesthetes with at least one synaesthesia subtype involving vision as the concurrent modality (e.g., synaesthetes with grapheme–colour synaesthesia or sequence–space synaesthesia; from now on labelled as –visual synaesthetes) were tested on a multimodal conflict task in which vision was the task-irrelevant modality. The CCT was therefore aimed at measuring the same cognitive components engaged during synaesthetic filtering. We predicted that if synaesthetes' constant need to disregard their automatic and irrelevant synaesthetic associations is generalised to other non-synaesthetic multimodal stimuli, they should show a smaller CE in the CCT compared to non-synaesthetes, reflecting enhanced intermodal selective attentional abilities.

In addition, to assess general filtering skills differences between synaesthetes and non-synaesthetes, we asked participants to perform the Eriksen flanker task (FT; Eriksen and Eriksen, 1974). The FT is a well-established paradigm that has been widely used to assess distractor inhibition and response competition (see Eriksen, 1995 for an historical review) and a variation of this task is part of the attention network task (ANT), which is routinely used to measure the executive control network of attention in developmental and clinical settings (e.g., MacLeod *et al.*, 2010). Participants are typically asked to make speeded choice responses to a central target whilst ignoring the irrelevant distractors (flankers) presented at the periphery. Targets and distractors are mapped to congruent and incongruent conditions and the flanker effect (FE) (i.e., difference in mean reaction times and error rates between incongruent and congruent trials) reveals the difficulty to ignore the irrelevant distractors and thus the strength of participants' filtering abilities. If the cognitive mechanisms activated during the management of irrelevant synaesthetic sensations and irrelevant information in the flanker task are at least partially overlapping, synaesthetes should also show an advantage at distractor filtering in the FT.

2. Material and methods

2.1. Participants

Sixteen –visual synaesthetes and 18 age-matched non-synaesthetes participated in the study (demographics are reported in Table 1). All synaesthetes experienced at least one synaesthesia subtype involving vision as the concurrent modality. Two additional synaesthetes were excluded from the study for failing this criterion. All participants reported no known neurological illness and normal or corrected-to-normal vision. The study was approved by The University of Edinburgh's Psychology Research Ethics Committee and followed the ethical guidelines laid down in the Helsinki Declaration. Participants were recruited via the University's employment website and convenience sampling, and they received a small monetary compensation (£7–12). Informed consent was obtained from all participants.

Table 1.

Descriptives and chi-square (χ^2) and *t*-statistics of the groups' demographics.

	Synaesthetes	Non-synaesthetes	Statistics
N (male)	14 (2)	14 (4)	$\chi^2(1) = 0.55$, $p = 0.46$
Age (SD)	25.7 (2.77)	24.1 (2.34)	$t(32) = 1.86$, $p = 0.072$
Handedness (left)	15 (1)	18	$\chi^2(1) = 1.16$, $p = 0.28$
Nº of native languages* (SD)	1.13 (.34)	1.22 (.55)	$t(32) = 0.61$, $p = 0.545$
Level of education** (SD)	3 (.73)	2.83 (.62)	$t(32) = 0.72$, $p = 0.48$

N = Sample size; SD = Standard Deviation.
* Nº of native languages: 1 = Monolingual, 2 = Bilingual, 3 = Polylingual.
** Level of education: 1 = High School, 2 = Undergraduate, 3 = Master, 4 = PhD, 5 = Postdoc.

Almost all of the synaesthetes reported multiple types of synaesthesias. The majority of them experienced synaesthesias related with –colour (as the concurrent) and/or sequence–space synaesthesias. Some of them also experienced ticker-tape synaesthesia (i.e., seeing spoken words or thoughts as 'subtitles'; e.g., Chun and Hupé, 2013), mirror synaesthesias (i.e., experiencing tactile sensations in response to other people being touched or getting hurt; e.g., Ward and Banissy, 2015), or ordinal–linguistic personification synaesthesias (i.e., attribution of personalities and/or genders to linguistic sequences such as numbers or letters; Simner and Holenstein, 2007) (see Table 2 for a detailed summary of the types of synaesthesias presented by each participant).

Table 2.

Detailed summary of the types of synaesthesias and Synesthesia Battery scores (when applicable) presented by each participant of the synaesthete (S) group.

Participant	–colour	SSS	Other –visual	Mirror–	OLP
S1	emotions	months			letters

	flavours odours personalities	notes weeks			numbers
S2	months (0.69) weekdays (0.70) years	months numbers weeks years			
S3		alphabet months notes numbers weeks years			
S4	letters (0.52) months (0.75)				letters numbers
S5	months (0.33) numbers (0.98)				
S6		alphabet months numbers weeks years	music–patterns		
S7	months (0.59) numbers (0.49) weekdays (0.78) years	alphabet hours months numbers weeks years			numbers
S8		months numbers weeks			
S9	letters (0.38) letters — Chinese (0.50) numbers (0.38) weekdays (0.48)				
S10	pain	months numbers weeks			
S11		months			
S12	months (0.72) weekdays (0.74)			touch pain	
S13		months years	ticker-tape		
S14	weekdays (0.55)				
S15	letters (0.43) music (0.605) numbers (0.43) words	alphabet months notes numbers weeks years	music–patterns voices–patterns		
S16	personalities voices weekdays	numbers years			letters

Numbers in brackets correspond to the scores obtained in the Synesthesia Battery (Eagleman *et al.*, 2007) by each participant. SSS = Sequence–space synaesthesias, OLP = Ordinal linguistic personifications.

Participants were divided into synaesthetes and non-synaesthetes following the completion of an ad-hoc synaesthesia screening interview adapted from Banissy *et al.* (2009) and Kusnir and Thut (2012). The interview thoroughly explored all currently known types of synaesthesia (Day, 2014) inquiring about the frequency, constancy, location, and stability people selfreportedly experienced each type of synaesthetic association. Participants who manifested some type of grapheme–colour or sound–colour synaesthesia further completed the Synesthesia Battery (SB) (Eagleman *et al.*, 2007). The SB is a standardised battery which measures the internal consistency of the synaesthetic experience for colour for several triggers including letters, numbers, weekdays, months, piano scale, chords, and instruments. Scores below 1.0 indicate the presence of synaesthesia, whereas scores of 1.0 or above indicate the absence of it. Synaesthetes who completed the test obtained, on average, a score of 0.60 points (the specific scores obtained by each participant who completed the SB can be found in Table 2). Following the methodological procedures of previous studies (e.g., Havlik *et al.,* 2015; Price, 2009; Rizza and Price, 2012), participants who responded yes to the interview question “Do you see any of the following items as being arranged in specific patterns in space? I.e., the alphabet, the days of the week, the months, the numbers, the musical notes, and/or other”, were further prompted to describe (i.e., “How often do you see it?”, “Does the arrangement always have the same pattern?”, “Where do you see it?”, “When did you start seeing it?”, etc.) and to draw their sequences. The descriptions and drawings were analysed in detail and their phenomenology was established consistent with the proprieties of synaesthesia in general and of space–sequence synaesthesias in particular (e.g., Cytowic, 2002; Price and Mentzoni, 2008; Sagiv *et al.*, 2006). All synaesthetes were classified as ‘associators’ (i.e., perception of the synaesthetic sensations in their ‘mind’s eye’ — as opposed to ‘projectors’, who experience them outside their body; Dixon *et al.*, 2004), after being specifically asked about the locus of their synaesthetic perceptions through relevant questions adapted from previous studies (e.g., Rouw and Scholte, 2007; Skelton e*t al.,* 2009): e.g., “Do you see the colours superimposed on the letters? Or are the letters not coloured, but you are aware that they have specific associated colours?”

2.2. Experimental Process

The study took place in a dimly lit, sound attenuated room. Participants sat in a comfortable chair and rested their heads in a chinrest to maintain a constant distance from the stimuli displays. Stimuli presentation for both tasks was controlled and responses were recorded via E-Prime 2.0® software and hardware (Serial Response Box 200A®, Psychology Software Tools).

Each participant performed the two tasks: the cross-modal congruency task (CCT) and the flanker task (FT). The order of the tasks, as well as the stimulus-to-response mapping for the CCT task (see Section 2.2.1), were counterbalanced between participants. Before the beginning of each task, participants completed a practice block (12 trials) which was repeated if necessary. The study lasted approximately 60 minutes.

2.2.1. Cross-Modal Congruency Task (CCT)

The CCT task was based on Pavani *et al.*'s (2000) and Spence *et al.*'s (2004) studies. A black rectangular cuboid (70 × 35 × 35 mm) was positioned on the table in front of the participants (23 cm from the table edge where the chinrest was attached) and aligned with their body midline. Participants held the cuboid with the index finger and thumb of their dominant hand (placed on the top and bottom ends of the cuboid, respectively). Two tappers used to deliver the tactile targets were attached to the participants' hand, one to the index finger and one to the thumb (Miniature Solenoid Tappers-3 and Miniature Solenoid Controller-3.4® hardware, Mechanical and Electronic Solve). To mask the sound of the tappers, white noise (44.1 kHz frequency) was presented via headphones throughout the task at 60 dB(A). Two LED lights (diameter = 2 mm), used to present the visual distractors, were attached to the cuboid, one at the top and one at the bottom, next to the participants' fingers (controlled via Heijo Basic Visual Controller 291VISB® hardware, Heijo Research Electronics). A white pin at the centre of the cuboid served as fixation point.

Tactile and visual stimuli were presented in this task. On each trial, a tactile target was presented either to the top or bottom finger and consisted of three 50 ms onset periods during which a rod made contact with the skin, interleaved by two 50 ms offset periods. The visual distractor (illumination of the top or bottom LED) consisted of three successive 50 ms green flashes separated by two 50 ms offset periods (250 ms total duration). Each trial started with the presentation of the stimuli (250 ms), followed by a 1,550 ms empty interval in which responses were collected (total response window of 1,800 ms following stimulus onset), and by a variable inter-trial interval (ITI) randomly selected between 100 and 500 ms. Three different types of trials were presented: congruent, incongruent, and neutral. The tactile target and the visual distractor were simultaneously presented from the same location (top or bottom) on congruent trials, and from opposite locations (tactile stimulus top and visual stimulus bottom location, or vice-versa) on incongruent trials. On neutral trials, only the tactile target was presented (top or bottom location) (Fig. 1).

Participants were instructed to perform an elevation discrimination task reporting via pedal press the location (top/bottom) of the tactile targets while ignoring the visual distractors when present. Half of the participants had to press the left pedal with their toes to indicate top location and the right pedal with their heel to indicate bottom location, and the other half followed the opposite mapping. Participants were also instructed to continuously keep their gaze on the fixation point and to answer as rapidly and accurately as possible. Participants completed three experimental blocks of 96 trials. Within each block, congruent, incongruent, and neutral trials were equally likely (32 trials per type) and randomly intermixed.

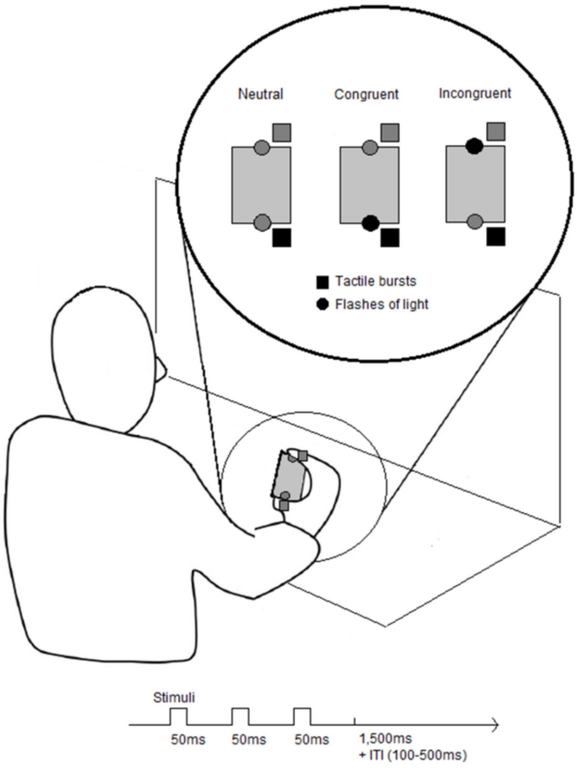


Figure 1. Display, type of trials, and time line of the cross-modal congruency task (adapted from Pavani *et al.*, 2000; Spence *et al.*, 2004); ITI: Inter-trial interval.

2.2.2. Flanker Task (FT)

The FT experimental task was based on Eriksen and Eriksen's (1974) design. Visual stimuli were presented on a computer monitor situated at a distance of 100 cm from the participant and consisted of black arrows (pointing left and right) and diamonds of 11.5 × 11.5 mm (0.66° of visual angle) on a light grey background.

The centrally presented left or right arrow (target) was flanked by two additional stimuli on each side (distractors). Distractors were diamonds on neutral trials, whereas they were left or right arrows on congruent and incongruent trials pointing to the same or opposite direction, respectively, as indicated by the target. Each trial started with the presentation of a central fixation cross (6 × 6 mm black cross) for a duration randomly selected between 300 and 500 ms, followed by the display of the stimulus array for 100 ms. There was a total response window of 1,000 ms following stimulus onset and a variable ITI randomly selected between 500 and 700 ms (Fig. 2).

Participants were instructed to report via button press (keys 1 and 2 of the Serial Response Box, operated by the left and right index fingers) the direction (left versus right) of the target (central arrow) while ignoring the distractors (flanking stimuli). Participants completed three blocks of 96 trials and within each experimental block, congruent, incongruent, and neutral trials were equally likely (32 trials per type) and presented in a randomised order.

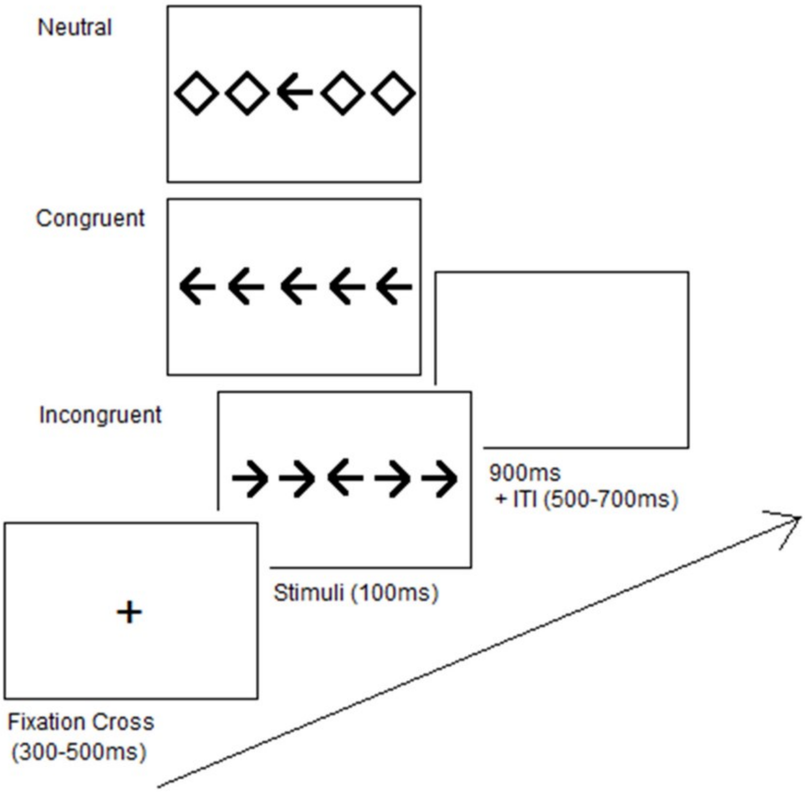


Figure 2. Type of trials and time line of the flanker task (adapted from Eriksen and Eriksen, 1974); ITI: Inter-trial interval.

2.3. Data Analyses

For both tasks, separate error rates (ER) and reaction times (RT) analyses were conducted. Responses exceeding ±3 standard deviations from the mean (calculated separately for each participant; e.g., Igarashi *et al.*, 2007) were considered as outliers and excluded from both ER and RT analyses. In the error analyses, ERs reflected the percentage of choice errors in each task after removal of omissions (i.e., no response trials) and outliers. In the RT analyses, mean responses were calculated after omissions, outliers, and choice errors were excluded. Mean ER and RT were then calculated for each type of trial and participant and analysed with mixed analyses of variance (ANOVAs) with 'Trial type' (neutral, congruent, and incongruent) as within-subjects factor and 'Group' (synaesthetes and non-synaesthetes) as between-subjects factor (Note 1). Further pairwise comparisons and independent *t*-tests were carried out as appropriate following significant effects. Whenever necessary, *p*-values were adjusted for multiple comparisons with the Bonferroni correction, and the Greenhouse–Geisser estimates of sphericity were used to report the results of the mixed ANOVAs when Mauchly's tests indicated that the assumptions of sphericity had been violated.

3. Results

3.1. Cross-Modal Congruency Task (CCT)

Outliers and omissions were excluded from the analysis (3.10% of the total trials). Overall, low ER were observed in both groups ($M = 3.24$, SD = 4.16 for synaesthetes and $M = 3.43$, SD = 3.38 for non-synaesthetes) and the analysis revealed no statistical differences between them [$F(1,32) = 0.022$, $p = 0.88$]. The main effect of 'Trial type' [$F(1.04,33.25) = 21.4$, $p < 0.001$, $\eta_p^2 = 0.40$] indicated the presence of higher ER on incongruent ($M = 8.39$, SD = 9.83) than congruent [$M = 0.63$, SD = 1.19; $t(33) = 4.925$, $p < 0.001$; $d = 1.11$] or neutral trials [$M = 1.01$, SD = 1.37; $t(33) = 4.56$, $p < 0.001$; $d = 1.05$)], and no differences were found between congruent and neutral trials [$t(33) = 1.48$, $p = 0.15$]. The interaction between 'Trial type' and 'Group' was not significant [$F(1.04,33.25) = 0.17$, $p = 0.69$] (see Fig. 3A, bar graph).

The RT analysis revealed a main effect for the factor 'Group' [$F(1,32) = 4.26$, $p = 0.047$], indicating that, overall, synaesthetes were faster than non-synaesthetes [$M = 555$, SD = 102 and $M = 633$, SD = 118, respectively; $t(32) = 2.01$, $p = 0.047$; $d = 0.71$]. As expected, significant differences emerged also between trial types [main effect of 'Trial type', $F(1.16,37) = 118$, $p < 0.001$, $\eta_p^2 = 0.79$]. Follow-up pairwise comparisons showed that RT were significantly slower for incongruent ($M = 686$, SD = 148) than for congruent [$M = 550$, SD = 108; $t(33) = 11.1$, $p < 0.001$; $d = 1.05$] and neutral trials [$M = 553$, SD = 104; $t(33) = 10$, $p < 0.001$; $d = 1.04$]. No significant differences were found between congruent and neutral trials [$t(33) = 0.77$, $p = 0.45$]. Importantly, a significant interaction was observed between 'Trial type' and 'Group' [$F(1.16,37) = 5.60$, $p = 0.019$, $\eta_p^2 = 0.15$]. Follow-up independent *t*-tests conducted separately for each type of trial revealed significant differences between synaesthetes and non-synaesthetes on incongruent trials [*M* = 624, SD = 115 and *M* = 741, SD = 155, respectively; *t*(32) = 2.48, *p* = 0.019; *d* = 0.86], but not on congruent [*M* = 518, SD = 103 and *M* = 579, SD = 107, respectively; *t*(32) = 1.69, *p* = 0.10] or neutral trials [*M* = 523, SD = 100 and *M* = 580, SD = 103, respectively; *t*(32) = 1.65, *p* = 0.11] (Fig 3A, line graph; Note 2).

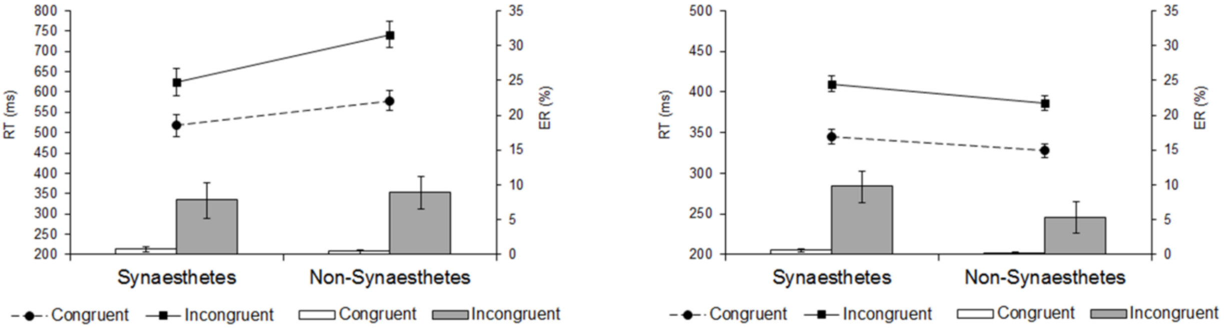
To further investigate this finding and to quantify our effect of interest, the congruency effect (CE) (i.e., incongruent minus congruent trials average RT) was calculated for each subject (the individual scores can be consulted in Table 3). This measure was then submitted to a separate one-way ANOVA with 'Group' as between-subjects factor. The CE analysis showed a main effect of 'Group' [*F*(1,32) = 6, *p* = 0.020, $\eta_p^2 = 0.16$], revealing a reduced CE in synaesthetes compared to non-synaesthetes (*M* = 106, SD = 60.2 and *M* = 162, SD = 71.4, respectively; *d* = 0.85) (Fig. 3A, line graph).

3.2. Flanker Task (FT)

After removing omissions and outliers (1.41% of the total trials), the ER analysis revealed no reliable differences between groups [*F*(1,32) = 2.45, *p* = 0.12]; overall ER: *M* = 3.94, SD = 4.63 for synaesthetes and *M* = 2.03, SD = 2.06 for non-synaesthetes. The main effect of 'Trial type' [*F*(1.04,33.2) = 20.8, *p* < 0.001, $\eta_p^2 = 0.39$] reflected the presence of a Flanker effect (FE). Specifically, ER were significantly higher on incongruent (*M* = 7.48, SD = 9.37) than congruent [*M* = 0.43, SD = 1; *t*(33) = 4.47, *p* < 0.001; *d* = 1.06] and neutral trials [*M* = 0.86, SD = 1.79; *t*(33) = 4.50, *p* < 0.001; *d* = 0.98]. No significant differences were found between congruent and neutral trials [*t*(33) = 1.65, *p* = 0.11]. No 'Trial type' × 'Group' interaction emerged to be significant [*F*(1.04,33.2) = 1.57, *p* = 0.22] (see Fig. 3B, bar graph).

In the RT analysis, the presence of the FE was confirmed by the significant main effect on 'Trial type' [*F*(1.33,42.5) = 285, *p* < 0.001, $\eta_p^2 = 0.90$]. Follow-up pairwise comparisons indicated that RT were significantly slower for incongruent trials (*M* = 397, SD = 40.1) compared to congruent [*M* = 336, SD = 35.4; *t*(33) = 18.6, *p* < 0.001; *d* = 1.63] and neutral trials [*M* = 342, SD = 34.9; *t*(33) = 16.4, *p* < 0.001; *d* = 1.48]. Neutral trials were also found to be significantly slower than congruent trials [*t*(33) = 4.08, *p* < 0.001; *d* = 0.18]. No differences were found between groups, as indicated by the lack of a significant 'Group' main effect [*F*(1,32) = 2.29, *p* = 0.14] or a 'Trial type' × 'Group' interaction [*F*(1.33,42.5) = 1.40, *p* = 0.25] (Fig. 3B, line graph).

A further one-way ANOVA assessing directly whether our theoretical measure of interest, the FE (i.e., incongruent minus congruent trials average RT), differed between groups, confirmed statistically similar FEs in synaesthetes and non-synaesthetes [*F*(1,32) = 1.10, *p* = 0.30) (Fig. 3B, line graph) (the specific FE scores for each participants can be consulted in Table 3).



A CCT

B FT

Figure 3. (A) CCT Mean reaction times (RT; lines) in ms and mean error rates (ER; bars) in percentages, and their corresponding SEM (error bars), for congruent and incongruent trials of the cross-modal congruency task; separately for each group. Both the ER and RT analyses revealed a main effect of the factor 'Trial type' ($p < 0.001$), evidencing a typical congruency effect (CE) (i.e., incongruent trials presented slower RT and higher ER than congruent trials). There was also an interaction between 'Trial type' and 'Group' ($p = 0.019$) in the RT analysis (and showed a similar tendency in the ER analysis). Specifically, synaesthetes presented faster RT for incongruent trials compared to non-synaesthetes. The determination of a significant smaller CE for synaesthetes ($p = 0.020$) confirmed this difference. (B) FT Mean reaction times (RT; lines) in ms and mean error rates (ER; bars) in percentages, and their corresponding SEM (error bars), for congruent and incongruent trials of the flanker task and for each group. There was only a main effect of the factor 'Trial type' ($p < 0.001$), reflecting the presence of a classic congruency effect (i.e., incongruent trials presented slower RT and higher ER than congruent trials).

Table 3.
Congruency effects (CE) (reaction time differences in milliseconds between incongruent and congruent trials) for the cross-modal congruency task (CCT) and the flanker task (FT) obtained by each participant.

Synaesthetes CE			Non-Synaesthetes CE		
	CCT	FT		CCT	FT
S1	56.03	97.1	NS1	315	92.2
S2	162	51.3	NS2	209	64.2
S3	77.45	18.4	NS3	53.1	78.1
S4	156	61.6	NS4	156	50.7

S5	206	74.7	NS5	271	70.5
S6	206	47.3	NS6	110	61
S7	120	85.7	NS7	140	61.1
S8	48	49.5	NS8	103	70.6
S9	75.6	56.1	NS9	187	69.8
S10	5.25	67	NS10	146	17.95
S11	27.4	59.6	NS11	49	42.8
S12	148	102	NS12	124	58
S13	139	65.3	NS13	182	47.7
S14	113	86.3	NS14	268	64.7
S15	98.6	61.5	NS15	118	22.3
S16	63.7	62.5	NS16	182	64.9
			NS17	128	53.45
			NS18	182	61.6

4. Discussion

To investigate whether synaesthetes have enhanced distractor filtering abilities, we measured different aspects of their attentional skills in two separate conflict tasks. First, we compared synaesthetes and controls' performance on the cross-modal congruency task (CCT), in which the relevant tactile target is always accompanied by an irrelevant visual distractor. In this task, participants have to prioritise one sensory modality over the other and the extent to which visual distractors interfere with the processing of the tactile target can be considered a measure of their intermodal selective attention abilities. In addition, we also measured participants' attentional filtering abilities with the classic Eriksen flanker task (FT). This allowed us to measure their general distractor filtering abilities with a standard task typically used to engage the executive control network of attention, thus contributing to the current debate regarding synaesthetes' general executive skills. Importantly, only –visual synaesthetes were tested in this study (i.e., synaesthetes with at least one synaesthesia subtype triggering visual concurrents, such as grapheme–colour synaesthesia or sequence–space synaesthesia) to ensure that their synaesthetic attentional filtering experience matched the sensory modality of the task-irrelevant distractors in our tasks.

The results of the FT revealed no difference between the congruency effects measured in –visual synaesthetes and controls. A robust flanker effect was observed in both groups with slower responses on incongruent than congruent trials, but the task-irrelevant distractors slowed participants' performance on incongruent trials in a similar way in both groups. Thus, the sample of synaesthetes and non-synaesthetes selected to take part in this study had comparable general executive control as measured in the FT. This result (or lack thereof) is in line with previous studies that used different classic conflict task (e.g., Stroop task, flanker task) to measure synaesthetes' attentional abilities and failed to report reliable differences with controls in the majority of cases (Mattingley *et al.*, 2001; 2006; Rouw *et al.*, 2013). Importantly, however, a very different pattern of results emerged in CCT, in which a reduced congruency effect (CE) was observed in –visual synaesthetes compared to controls. The difference between the CEs in the two groups was driven by faster response times on incongruent trials in synaesthetes than in non-synaesthetes, while no difference was observed for congruent or neutral trials. This specific pattern of results indicates that –visual synaesthetes were able to select and execute the correct response more quickly than controls when conflicting information coming from different sensory modalities was presented, suggesting that they were better at ignoring the irrelevant visual stimuli of the CCT. This finding is consistent with other studies that investigated synaesthetes' susceptibility to multisensory illusions (double-flash illusion — Neufeld *et al.*, 2012; McGurk illusion — Sinke *et al.*, 2014), showing that synaesthetes experienced fewer multisensory illusions than non-synaesthetes (but see Whittingham *et al.*, 2014 and Brang *et al.*, 2012 for different outcomes). Our findings expand the existing literature and provide the first direct evidence that –visual synaesthetes are more efficient than controls at dissociating conflicting information from different sensory modalities in a cross-modal task in which the irrelevant sensory modality matches their synaesthetic concurrents.

Taken together, the results of the present study support the hypothesis that synaesthetes' constant need to ignore their irrelevant synaesthetic percepts is associated with enhanced selective attentional skills. This attentional ability seems to impact synaesthetes' cognitive skills beyond the person's immediate synaesthetic experiences. Crucially, however, this advantage seems to only extend to other types of non-synaesthetic multisensory stimuli, as revealed by the significant advantage observed in a cross-modal congruency task and the lack of effects found in the FT, which measures participants' general executive efficiency. The different pattern of results observed in two seemingly similar conflict tasks might suggest that while the mechanisms responsible for synaesthetic attentional filtering (that is, those underlying the inhibition of irrelevant synaesthetic sensations) are at least partially overlapping with the mechanism engaged during our cross-modal congruency task, they are mostly independent from the mechanisms responsible for the management of other types of perceptual conflict such as those involved in flanker tasks. Indeed, several lines of research seem to suggest that similar mechanisms might be responsible for multisensory perception in the general population and inducer-concurrent associations in synaesthetes (e.g., Sagiv and Ward, 2006). If this is the case, experiencing a synaesthetic concurrent would be equivalent to perceiving a stimulus in an irrelevant sensory modality and synaesthetes might be particularly capable to focus on a certain stimulus modality while ignoring another (intermodal attention). Interestingly, intermodal attention is independent from other attentional mechanisms based on spatial selectivity (e.g., Eimer and Schröger, 1998; Hötting *et al.*, 2003). This could explain why no synaesthetic advantages were observed in the FT, in which spatial mechanisms are primarily used to select the target from the distractors (e.g., Fan *et al.*, 2003).

This study represents a first attempt to investigate synaesthetes' intermodal attentional abilities. One relevant question which remains to be explored concerns the exact mechanisms responsible for the differences observed between synaesthetes and controls. Does synaesthetes' constant need to ignore their automatic synaesthetic percepts cause a 'synaesthetic attentional training'? Or is the synaesthete's attentional profile intrinsically distinct from the general population? Changes over the life span in synaesthetes' intermodal attentional abilities might support the 'training' hypothesis. In particular, one might expect that these attentional abilities depend on the amount of synaesthetic interference to which synaesthetes are exposed. Older synaesthetes, which have experienced irrelevant percepts for a longer period of time, should be better than younger ones at filtering out irrelevant information. According to this hypothesis then, a negative correlation should be expected between age and CE. While the age range of synaesthetes in the present study was too narrow (21 to 31 years old) to provide meaningful insight into this question, it is worth noting that there is evidence showing that the number of audio-visual double-flash illusions experienced by synaesthetes is negatively correlated with age (Neufeld *et al.*, 2012). Furthermore, evidence from the other end of the age spectrum shows that children with grapheme–colour synaesthesia experience difficulties in numerical tasks due to cognitive interference caused by digits presented in colours incongruent to their synaesthetic associations (Green and Goswami, 2008). These findings might suggest that synaesthetes attentional abilities are improved over time in a use-dependent fashion. That is, synaesthetes learn to deal with their synaesthetic concurrents. However, indirect evidence from associative learning studies in synaesthetes casts some doubts about the 'training' hypothesis (Bankieris and Aslin, 2016a, b). In these studies, while synaesthetes performed better than non-synaesthetes in an explicit associative learning task, they seemed to experience greater interference during an implicit associative learning task. If synaesthetes learn to ignore their synaesthetic concurrents, they should be particularly able to train their attentional systems to ignore other irrelevant information (i.e., they should be less affected by interference). Future studies in this area are necessary to further evaluate these alternative hypotheses.

These considerations are linked to another critical question: Can synaesthetes intermodal filtering abilities be generalised beyond the modality of their synaesthetic concurrents? As described, in the present study –visual synaesthetes were better than non-synaesthetes at ignoring a task irrelevant visual stimulus that was presented simultaneously to a target in a different sensory modality. Because we tested –visual synaesthetes is unclear whether synaesthetes which experience non-visual concurrents would show analogous advantages for visual stimuli. If synaesthetic attentional abilities are learned, they might be generalised to other sensory modalities. In contrast, if synaesthetes' attentional system is intrinsically different for the sensory modality of their concurrent, no generalisation to other modalities should be observed. Neuroimaging evidence suggests that the recruitment of parietal areas is shared by different types of synaesthesias (e.g., see Rouw *et al.*, 2011 and Specht, 2012 for reviews). However, specific brain areas are also involved in particular synaesthetic sensations, such as the activation of the colour region V4 in synaesthetic colour experience (e.g., Hubbard *et al.*, 2005; Nunn *et al.*, 2002; Sperling *et al.*, 2006; Steven, 2006; Van Leeuwen, 2010). Future studies should directly address this point by assessing the filtering abilities of –visual and non-visual synaesthetes in different attentional tasks in which the task-irrelevant distractor matches and does not match the sensory modality of their concurrents.

While all our synaesthetes had visual concurrents, they experienced different types of synaesthesia. Following a reviewer's suggestion, we explored the interesting possibility that different types of –visual synaesthetes might show different degrees of filtering abilities. Given that the synaesthetes tested in the present study presented either a –colour or a sequence–space synaesthesia (or both) and that previous research observed systematic differences in the visual ability of these two types of synaesthetes (Ward *et al.*, 2016), synaesthetes were in three groups: only-colour (subjects who only experienced synaesthesias producing –colour concurrents; e.g., grapheme–colour synaesthesia), only-SSS (participants who only experienced sequence–space synaesthesias; e.g., calendar–forms), and colour&SSS (subjects who experienced both previous types). An orthogonal 2 × 2 between-subjects factorial design (–colour: yes/no; SSS: yes/no) was used — the no-colour and no-SSS group corresponding to non-synaesthetes. The CE measured in the CCT (RT differences in milliseconds between incongruent and congruent trials) was submitted to a two-way ANOVA. Interestingly, the analysis revealed a significant main effect of SSS [$F(1,30) = 5.075$, $p = 0.032$, $\eta_p^2 = 0.145$], but not of colour [$F(1,30) = 0.52$, $p =$

0.475] nor a –colour × SSS interaction [$F(1,30) = 0.020$, $p = 0.89$]. This analysis showed that the CE was significantly reduced in participants with SSS compared to non-SSS participants ($M = 91.2$, SD = 60.7 and $M = 157$, SD = 66.8, respectively). These findings suggest that a specific subgroup of synaesthetes, namely those with SSS, was the one with strongest intermodal attentional filtering advantages. While this appears to be a promising line for future research, it should be highly stressed that this was a post-hoc analysis and that the samples were not only small, but also unbalanced (11 subjects with SSS and 23 without). For this reason, the question of possible differences between different synaesthete group subtypes should be further confirmed in future studies with appropriate samples.

Finally, it is relevant to note that all the synaesthetes tested in this study were associators. Whilst associators experience their synaesthetic concurrents 'in the mind's eye', projectors report these experiences in external space (Dixon *et al.*, 2004). There is contradictory evidence regarding behavioural advantages of projector over associator synaesthetes (e.g., Dixon *et al.*, 2004; Rothen and Meier, 2009; Ward *et al.*, 2007) or about the existence of neural differentiation between the two groups (e.g., Rouw and Scholte, 2007; 2010). Nonetheless, different synaesthetic experiences could potentially imply different attentional processing strategies: Do projectors' ostensibly stronger synaesthetic interference cause stronger filtering abilities compared to associators? Or does this special synaesthetic experience make them less successful at ignoring their percepts and, hence, they have weaker filtering abilities? Future studies assessing different types of synaesthetes and different types of stimuli should clarify all these points.

In sum, the present study has provided the first evidence that –visual synaesthetes are less affected than non-synaesthetes by the presentation of task-irrelevant visual stimuli when they have to focus on a different sensory modality (as measured in a cross-modal congruency task). This finding suggests that synaesthetes might have enhanced intermodal attentional abilities which allow them to ignore or supress the irrelevant information coming from their synaesthetic concurrents. The present results broaden our understanding of synaesthesia's effects on cognition in a research area which remains largely unexplored.

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Notes

1. Due to technical problems with the stimuli presentation software, only trials in which a left-pointing target was presented could be included in the analyses (differences between left and right trials were previously checked and rejected).
2. Following a reviewer's suggestion, an additional mixed ANOVA for the median RT of the CCT was carried out to confirm the robustness of the effects observed for the mean RT analyses across different measures of central tendency. The results revealed an analogous interaction between 'Trial type' and 'Group' [$F(1.09,34.9) = 6.41$, $p = 0.014$, $\eta_p^2 = 0.17$], equally driven by the faster RT for synaesthetes compared to non-synaesthetes on incongruent trials [$M = 611$, SD = 113 and $M = 734$, SD = 151, respectively; $t(32) = 2.67$, $p = 0.012$; $d = 0.92$]. The main effects of 'Trial type' and 'Group' were also ratified [$F(1.09,34.9) = 107$, $p < 0.001$, $\eta_p^2 = 0.77$ and $F(1,32) = 4.425$, $p = 0.043$, $\eta_p^2 = 0.12$, respectively]. Specifically, incongruent trials ($M = 676$, SD = 146) were slower than both congruent [$M = 535$, SD = 107; $t(33) = 10.2$, $p < 0.001$; $d = 1.10$] and neutral trials [$M = 535$, SD = 107; $t(33) = 9.575$, $p < 0.001$; $d = 1.08$]; and synaesthetes showed overall faster RT compared to non-synaesthetes ($M = 542$, SD = 103 and $M = 620.5$, SD = 114, respectively; $d = 0.73$).

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