



Spatial cueing in time–space synesthetes: An event-related brain potential study

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ABSTRACT

Some people report that they consistently and involuntarily associate time events, such as months of the year, with specific spatial locations; a condition referred to as time–space synesthesia. The present study investigated the manner in which such synesthetic time–space associations affect visuo-spatial attention via an endogenous cuing paradigm. Reaction times and ERPs were recorded as 12 time–space synesthetes and 12 control participants did a peripheral target detection task, cued by three different types of centrally presented cues: arrows pointing left or right, direction words “left” or “right”, and month names associated with either the left or the right side of the synesthete’s mental calendar (e.g., “October” or “May”). Cues were followed by probes on the left or right side of the screen, and participants responded to the probes with button presses. Behavioral and ERP data suggested that for synesthetes, month words functioned more effectively as cues to direct attention in space. In synesthetes but not controls, a comparison of ERPs to probes cued by months revealed effects of cue validity on the P3b component peaking 370 ms post-onset and on the subsequent positive slow wave (pSW) observed 600–900 ms post-onset (both larger for invalid probes). No effects of cue validity were observed on early visual potentials (N1) for probes cued by months. The findings suggest that in these time–space synesthetes cue validity influenced post-perceptual processes, such as stimulus evaluation and categorization, with no evidence for enhanced visual processing.

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1. Introduction

Synesthesia is a condition in which certain types of perceptual or conceptual stimuli evoke involuntary and consistent sensations in another, unstimulated and seemingly unrelated modality (Baron-Cohen & Harrison, 1997; Cytowic, 1989/2002; Hubbard, Arman, Ramachandran, & Boynton, 2005; Ramachandran & Hubbard, 2001, 2003). In time–space synesthesia, units of time are experienced as occupying specific spatial locations such that temporal sequences (e.g. the months of the year) are felt to be arranged in a particular shape. These spatial representations are sometimes convoluted and idiosyncratic, but display the test–retest consistency that is the hallmark of synesthesia (Cytowic, 1989/2002; Galton, 1880/1997; Smilek, Callejas, Dixon, & Merikle, 2007). More typically, time–space synesthetes report the 12 months of the year to be arranged in the shape of an oval, an oblong, or a circle (Brang, Teuscher, Ramachandran, & Coulson, 2010; Galton, 1880/1997).

Time–space synesthesia, along with other kinds of synesthetic spatial forms for sequences (e.g., the sensation that numbers, letters of the alphabet, etc. are aligned on a convoluted path), perhaps constitutes a borderline case of synesthesia, since it is an internal experience generated by a cognitive state, rather than by sensory stimulation. Some authors have either included (Galton, 1880/1997) or excluded (Dehaene, 1997) these associations between temporal units and spatial forms as an instance of synesthesia. However, in view of these individuals’ descriptions of the involuntary, consistent, and idiosyncratic nature of time–space associations, and given that they are often observed in people who report other, more canonical synesthetic experiences (e.g. colored letters, or colored hearing; e.g., Sagiv, Simner, Collins, Butterworth, & Ward, 2006), most researchers now do include time–space synesthesia as a valid form of the condition (e.g., Grossenbacher & Lovelace, 2001; Hubbard, Piazza, Pinel, & Dehaene, 2005; Price & Mentzoni, 2008; Sagiv et al., 2006; Smilek et al., 2007).

Hubbard and Teuscher (2010) propose that time–space synesthesia is caused by cross-activation in parietal cortex, an area known to be involved in the processing of both temporal quantities (Coull, Vidal, Nazarian, & Macar, 2004; Lewis & Miall, 2002) and abstract spatial maps (see also the discussion of number-form synesthesia by Hubbard, Arman, et al. (2005) and Hubbard, Piazza, et al.

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(2005)). Abstract spatial maps are represented in posterior superior parietal lobes, which have also been implicated in spatial abilities (Cohen & Andersen, 2002; Colby & Goldberg, 1999). Although the neural substrate of time–space synesthesia is not currently known, it likely involves a complex interplay of activity in the angular gyrus (representing spatial forms ranging from number-lines to calendars, e.g. Göbel, Walsh, & Rushworth, 2001; Spalding & Zangwill, 1950) and activity in other parietal structures (including the intraparietal sulcus and more generally the temporal parietal occipital junction; Ramachandran and Hubbard, 2001). Grapheme–color synesthesia has been shown to be accompanied by an increase in white matter connectivity between brain areas thought to be important for grapheme and color perception, respectively (Rouw & Scholte, 2007). Accordingly, it is possible that an analogous increase in connectivity is present in time–space synesthesia.

Given the important role played by the parietal lobes in orienting attention in space (Behrmann, Geng, & Shomstein, 2004; Posner & Petersen, 1990), one implication of Hubbard and Teuscher's (2010) model is that the hypothesized increased connectivity in parietal lobes in time–space synesthetes may affect spatial attention processes. Due to the habitual involuntary associations in individuals with this condition, temporal concepts may trigger shifts of visuo-spatial attention to their associated regions in space. For example, when thinking about October, a time–space synesthete might naturally direct her attention to the region of space that she associates with October. This is consistent with a spatial cuing study by Smilek et al. (2007). In this paradigm, a cue stimulus (e.g. an arrow) directs the subject to attend to a particular location on each trial, and a target is then presented either at the attended location (valid trials), or at an unattended location (invalid trials) (Posner, 1978). In the so-called Posner paradigm, responses to targets are faster and more accurate when they appear at the cued (i.e. valid) than un-cued (invalid) location (e.g., Cheal & Lyon, 1991; Posner, 1980). Smilek and colleagues (2007) used a variant of the Posner task in which a centrally presented cue was equally likely to be followed by valid and invalid targets (Friesen & Kingstone, 1998). In light of the uninformative nature of the cues, faster responses to targets in the cued locations have been interpreted as signaling the reflexive nature of the attentional shift (Jonides, 1981). To test the reflexive nature of synesthetic spatial forms, Smilek et al. (2007) presented month words that synesthetes associated with the left and the right side of space as nonpredictive cues in their task. That is, probes were equally likely to occur in the cued and un-cued locations. Smilek and colleagues found that in two of the four time–space synesthetes they tested, responses were faster for targets in cued locations. In spite of the fact that the cues provided no information that could help participants perform the target detection task, these synesthetes nonetheless shifted their attention to the cued region of space. Moreover, these cuing effects were evident both at a long cue-target SOA (600 ms) and at a short cue-target SOA (150 ms), where strategic influences on performance should be nonexistent, since volitional shifts of attention typically emerge at cue-target SOAs greater than 300 ms (e.g., Friesen & Kingstone, 1998). Consequently, Smilek et al. (2007) argued that the associations in time–space synesthesia are such that temporal concepts automatically trigger a shift of attention to the appropriate region of space.

One reason Smilek and colleagues (2007) did not observe a higher incidence of cuing effects, however, may be their use of nonpredictive cues. Previous research on visuo-spatial attention has suggested a dissociation of voluntary, *endogenous* processes engaged by cues which are symbolic, centrally presented, and predictive, from reflexive, *exogenous* processes induced by nonpredictive cues presented in the periphery (see Funes, Lupianez, & Milliken (2007) for review). When centrally presented symbolic

cues are nonpredictive, they do not typically facilitate responses to stimuli in the cued region of space, as there is simply no motivation for the subject to shift attention to the cued location if the target is just as likely to occur in the un-cued one (Stevens, Pashler, & Yantis, 2004, pp. 241–242). In light of this, it is surprising that Smilek et al. found any cuing effects at all. Furthermore, exogenous processes have been linked to the superior colliculus, whereas endogenous processes have been linked to parietal regions that have also been implicated in time–space synesthesia (Rafal, Posner, Friedmann, Inhoff, & Bernstein, 1988; Rafal & Henik, 1994, though cf. Bartolomeo & Chokron, 2002). Consequently, we used predictive endogenous cues in the present task, to test whether synesthesia would affect canonical endogenous attentional processes.

As in the case of classic spatial cuing effects, the observation of facilitation in a reaction time task can be interpreted as reflecting either the operation of a perceptual gating function during early stages of processing (Posner, 1980), or as reflecting attentional changes in later, post-perceptual stages of processing (Sperling, 1984; Sperling & Doshier, 1986). By recording event-related brain potentials (ERPs) in conjunction with a spatial cuing task, previous investigators have determined that spatial cuing effects result both from the operation of perceptual gating, as shown by the fact that cued targets elicit larger amplitude visual potentials (e.g., P1 and N1), and from the operation of attention in post-perceptual stages, as reflected in cuing effects on late positive components in the ERP (e.g. the P3b) (Eimer, 1994; Luck & Hillyard, 1994; Mangun & Hillyard, 1991).

The present study was intended to explore the time course of spatial cuing in time–space synesthetes and non-synesthetic controls by recording ERPs during a prototypical endogenous cuing task with cues that were symbolic, centrally presented, and informative. Three different types of cues were employed: arrows pointing left or right; direction words “left” and “right”; and time units associated with either the left or the right region of space (e.g., “October”, which in one of our synesthetes was associated with the left side of space, and “May” which was associated with the right). Arrow cues were included because they have previously been shown to be effective in ERP studies of endogenous cuing (e.g. Eimer, 1997); direction words, which are verbal stimuli associated with particular regions of ego-centrally defined space, were used because they could be expected to effectively direct spatial attention in synesthetes and non-synesthetes alike.

Further, a number of precautions were taken to ensure that any observed differences between the synesthetes' and controls' ERPs could be attributed to synesthesia, as opposed to greater motivation on the part of the synesthetes. For example, all cues (arrows, direction words, and months) were predictive, as probes occurred in the cued location 75% of the time. Previous research with the Posner paradigm has indicated that validity rates of 75–80% produce the largest cuing effects and ensure that participants comply with instructions to shift their attention in response to the cue (Bowman, Brown, Kertzman, Schwarz, & Robinson, 1993; Jonides, 1980; Posner & Cohen, 1984). Each non-synesthete was paired with a different synesthete, was told which month cued which region of space (left or right), and viewed the exact same stimuli as the synesthete with whom s/he was paired.

We predicted that both synesthetes and non-synesthetic controls would show a similar pattern of ERP cuing effects following arrow and direction-word cues, but that the two groups' brain response would differ for time-unit cues. Based on previous ERP studies using similar spatial cuing paradigms (e.g., Donchin & Coles, 1988; Eimer, 1997; Hillyard, Vogel, & Luck, 1998; Mangun, 1995; Perchet, Revol, Fournieret, Mauguier, & Garcia-Larrea, 2001), we focused our predictions on the N1 and P3b components, as well as a positive slow wave (pSW).

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