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What spatial coordinate defines color-space synesthesia?

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ABSTRACT

Synesthesia is characterized by the association between different stimuli modalities. For example, in sequence-space synesthesia, numbers, weekdays, months, and musical tones are visualized in specific spatial locations. Although sequence-space synesthesia tends to co-occur with other types of synesthesia (e.g., grapheme-color), our knowledge about how these individuals represent space is still limited. A central issue for understanding spatial processing refers to the coordinate system used to represent spatial locations. We report on a space-color synesthete (N.W.) who vividly experiences colors in specific spatial locations. We used a task where N.W. and control subjects were required to report the location of a gray square relative to a colored square. The color of the square was task-irrelevant. Participants responded to the following trial types: (1) central trials, where one stimulus appeared on the left and the other on the right side of fixation, and (2) relative location trials, where both stimuli appeared either on the left or on the right side of fixation. Results showed that the color of the target had a strong impact on N.W.'s responses on both trial types, but not on the controls' responses. These results show that the spatial representation underlying N.W.'s synesthetic experience is automatic and sensitive to the relative location of objects.

1. Introduction

Synesthesia is characterized by an abnormal association in which a certain stimulus automatically induces an additional percept or association in another sensory modality. For example, letter and digits may elicit a vivid experience of colors or numbers may be visualized in specific spatial locations. The terms "inducer" and "concurrent" are used to refer to the event that triggers (e.g., letters) the specific sensory experience or association (e.g., colors), respectively. Among the most common types of synesthesia are the so-called grapheme-color synesthesia – in which letters, numbers, or days of the week are associated with specific colors (Alford, 1918; Cohen-Kadosh, Cohen-Kadosh, & Henik, 2007; Mattingley, Payne, & Rich, 2006; Mattingley, Rich, Yelland, & Bradshaw, 2001; Rich, Bradshaw, & Mattingley, 2005) – and spatial-form synesthesia, in which words, numbers, days of the week, or names of the months are visualized in specific spatial arrays (Eagleman, 2009; Galton, 1880; Piazza, Pinel, & Dehaene, 2006; Sagiv, Heer, & Robertson, 2006; Seron, Pesenti, Noël, Deloche, & Cornet, 1992; Gertner, Henik, & Kadosh, 2009; Arend, Gertner, & Henik, 2013; Diesendruck et al., 2010; Jarick, Dixon, Maxwell, Nicholls, & Smilek, 2009).

An interesting aspect concerning spatial-form synesthesia is that it tends to co-occur with other types of synesthesia, as for example, grapheme-color synesthesia (Sagiv et al., 2006). Despite the fact that space is an important dimension characterizing different forms of the synesthetic experience, our knowledge about how these individuals represent space is still limited.

A central issue for understanding spatial processing in general refers to the coordinate system used to represent spatial locations. For example, we know that individuals with synesthesia represent numbers in specific spatial locations, but it is still not clear what frame of reference defines spatial locations in spatial-form synesthesia, or in other words what defines "left" and what defines "right" spatial locations. Space is represented according to a number of coordinate systems or frames of reference that can be, for example, viewer based or environmentally centered (Andersen, Snyder, Bradley, & Xing, 1997). Interestingly, viewer-based coordinates can occur with respect to left side versus right side of the midline of the observer's body, but they can also occur with respect to yet another set of coordinates centered on the object itself (Marr, 1982; Marr & Nishihara, 1978). In an object-based frame of reference, left and right are defined with respect to the object itself. This type of spatial coding is advantageous because it allows objects to be processed with structural invariance across different

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orientations. Object-based spatial coding has been found in disorders of spatial attention, for example, in unilateral neglect (Behrmann & Moscovitch, 1994).

In the present study, we examine the spatial coordinate system that defines color-space association in synesthesia. We report on a single case of a synesthete (N.W.) who vividly experiences colors in specific spatial locations. Our aims are twofold: (1) to examine the impact of N.W.'s color-space association on her motor choices, in other words, to examine whether colors automatically elicit response locations; (2) to study the coordinate system or frame of reference that defines "left" space and "right" space in N.W.'s synesthetic experience. To achieve these goals, we used a task that required locating a colored square relative to a gray square. The specific color of the square was task-irrelevant. That is, the colors were not associated with any specific response. The following locations were possible: the colored square and the gray square could appear (1) on either the left side or the right side of the fixation cross (see Fig. 1, center condition); (2) both squares could appear on the left side of the fixation cross; (3) both squares could appear on the right side of the fixation cross (see Fig. 1, relative location condition). It is important to note that in the relative location conditions, the colored square could be located on the left side or on the right side of the gray square within the same visual field.

The present task shares a number of features with the Simon task (Nicoletti & Umiltá, 1989; Rubichi, Nicoletti, Iani, & Umiltà, 1997; Simon & Small, 1969). The Simon task involves an arbitrary mapping of color and response: Participants are asked to respond using their left and right hands for two different colors (e.g., press left for blue and press right for green). The stimulus is presented on the left or right side of a fixation cross. Even though the spatial location of the stimulus is task-irrelevant, it affects individual's responses: When the location of the stimulus and the location of the response correspond (Simon compatible), response times (RTs) are faster in comparison to when the location of the stimulus and the response do not correspond (Simon incompatible). In the task used here, participants are presented with a gray and a colored squared on the left or right side of a fixation cross. The task requires deciding the location of a gray square relative to a colored square (either blue or green in different trials). Different from the Simon task, there is no direct mapping involving the specific color of the square and the response. Because our task does not contain an arbitrary mapping involving color and response, controls are not expected to show a Simon-like effect. That is, there should be no effect involving the color of the target. We reason that if N.W.'s color-spatial association affects specific motor responses (blue → left and green → right), we should find faster RTs when color and spatial locations are congruent as opposed to when they are incongruent with her personal association. That is, N.W.'s synesthetic experience should produce a compatible Simon-like effect.

In addition, by manipulating the relative position of the colored target relative to the gray distractor within the visual field (see Fig. 1), we aim to explore how left and right spatial locations are defined in N.W.'s spatial representation. The effects of relative target location are particularly informative regarding how left and right locations are represented. For example, is the association blue → left coded with respect to N.W.'s body midline or does this

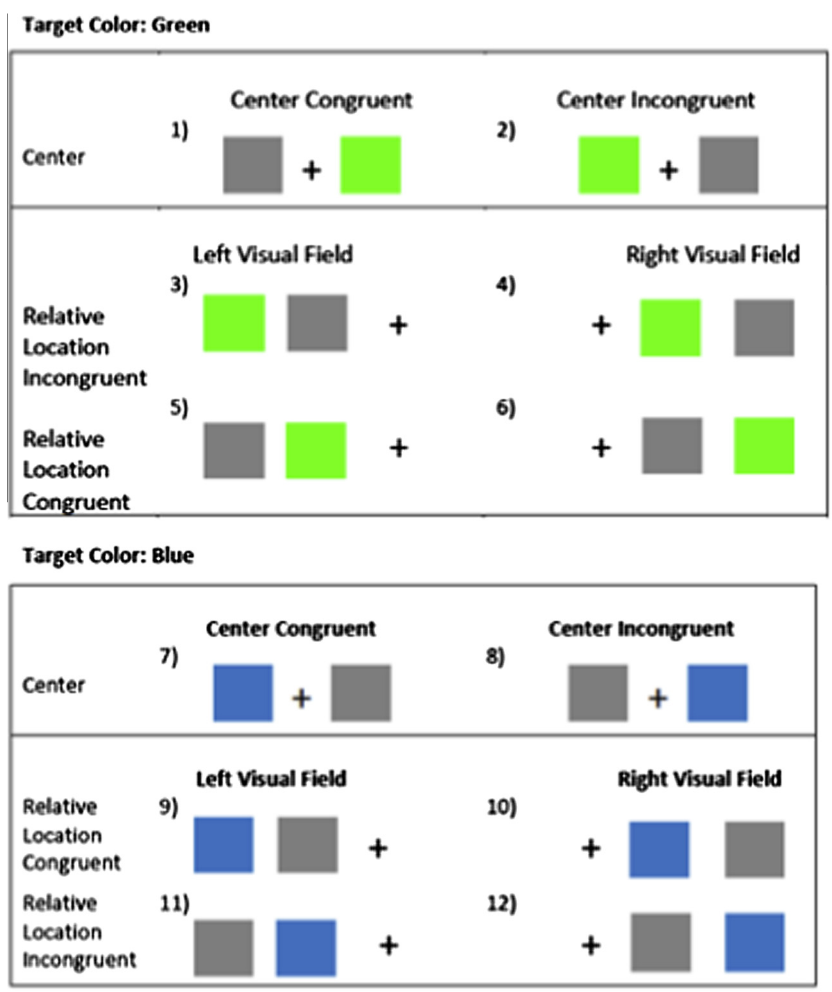

Fig. 1. Schematic representation of each trial type.