available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/cortex

Special section: Research report

The objectification of overlearned sequences: A new view of spatial sequence synesthesia

David M. Eagleman[a,b,*]

[a]Department of Neuroscience, Baylor College of Medicine, Houston, TX, USA
[b]Department of Psychiatry, Baylor College of Medicine, Houston, TX, USA

ARTICLE INFO

Article history:
Received 9 July 2008
Reviewed 2 April 2009
Revised 17 April 2009
Accepted 22 June 2009
Published online 7 July 2009

Keywords:
Synesthesia
Sequences
Reification
Temporal lobes
SNARC effect

ABSTRACT

In the phenomenon of spatial sequence synesthesia (SSS), subjects can articulate explicit spatial locations for sequences such as numbers, letters, weekdays, months, years, and other overlearned series. Similarly, abstract sequences can take on implicit spatial representations in non-synesthetes, as evidenced by the spatial numerical association of response codes (SNARC) effect. An open question is whether the two findings represent different degrees of the same condition, or different conditions. To address this, we developed computer programs to quantify three-dimensional (3D) month-form coordinates in 571 self-reported spatial sequence synesthetes; this approach opens the door for the first time to quantified large-scale analysis. First, despite the common assumption that month-forms tend to be elliptical, we find this to be true in only a minority of cases. Second, we find that 27% of month forms are in the shape of lines, consistent with the assumed shape of implicit spatial forms in the SNARC effect. Next, we find that the majority of month forms are biased in a left-to-right direction, also consistent with the directional bias in the SNARC effect (in Western speakers). Collectively, these findings support the possibility that SSS is directly related to the sequence representations in non-synesthetes. While the search for neural correlates has concentrated on areas in the parietal lobe involved in numeric manipulation and coordinate systems, we propose that the basis of this synesthesia may be the close proximity of temporal lobe regions implicated in sequence coding and visual object representation.

1. Introduction

Spatial sequence synesthesia (SSS) is a condition in which abstract sequences are automatically conceived as having physical two- or three-dimensional (2D or 3D) structures, like real-world objects (Galton, 1880, 1883; Bertillon, 1880; Seymour, 1980; Seron et al., 1992; Hubbard et al., 2005b; Sagiv et al., 2006; Cytowic and Eagleman, 2009). The conceived structures have typically been reported to bend, loop or zigzag in a variety of idiosyncratic shapes. Sir Francis Galton pointed out that the forms

> "are stated in all cases to have been in existence… as long back as the memory extends; they come 'into view quite independently' of the will, and their shape and position… are nearly invariable (Galton, 1883)".

* Baylor College of Medicine, Neuroscience, 1 Baylor Plaza, Houston, TX 77030, USA.
E-mail address: eagleman@bcm.edu
0010-9452/$ – see front matter © 2009 Elsevier Srl. All rights reserved.
doi:10.1016/j.cortex.2009.06.012

Digits of the numberline, letters of the alphabet, days of the week and months of the year are especially common forms, as are other ordinal sequences such as shoe sizes, Indian caste system, temperatures, historical eras, and prime time television line-ups (Seymour, 1980; Seron et al., 1992; Sagiv et al., 2006; Cytowic and Eagleman, 2009; Hubbard et al., 2005b). Even blind subjects can purportedly experience spatial sequence synesthesia (Wheeler, 1920). Some individuals possess a form for only one sequence; others have forms for more than a dozen (Hubbard et al., this issue, 2009; Cytowic and Eagleman, 2009).

Two important clues about the neural basis of spatial sequence synesthesia deserve highlighting at the outset: (1) spatial forms are composed of stimulus sets that are sequential and overlearned, and (2) the forms typically possess an internal coordinate system that allows different perspectives upon it, suggesting that forms are ''reified'', or coded as physical objects by the brain. We will turn to each of these points in turn and then combine them for a new theory about the neural basis of SSS.

1.1. *What is special about sequences?*

There has previously been an assumption that spatial sequence synesthesia is fundamentally tied to concepts of time. For example, Smilek and colleagues described the spatialization of months, weeks, and years under the term ''time-space synesthesia'' (Smilek et al., 2007). Despite the seduction of connecting ''time'' and ''space'' (as has been successful in physics), the linkage here erroneously intimates that *temporality* is the basis of the forms, rather than the *sequentiality* of the stimuli. The large variety of other spatialized sequences (alphabets, shoe sizes, caste systems, etc) indicates that time is not the critical property in question – instead, it is ordinality. Therefore this sentence hopes to represent the literature's final usage of the term ''time-space synesthesia.''

Instead, the elements that compose spatial forms implicate something unique about the neural basis of overlearned sequences. It has been long noted that the learned ordinal sequence is also a typical trigger for color synesthesias (Shanon, 1982; Rich et al., 2005), suggesting a possible common neural origin between grapheme-color synesthesia and SSS (Seron et al., 1992). In support of this hypothesis, many synesthetes experience their overlearned sequences with both color and location (Sagiv et al., 2006; Cytowic and Eagleman, 2009). Collectively, the properties of these types of synesthesia implicate something unique about the neural coding of overlearned sequences. Below, we will present data that point to the brain areas that are involved.

1.2. *What is the coordinate system of the forms? The case for reification*

Although forms are often thought of as fixed forms in relation to the body space, it is commonly reported that synesthetes can mentally take on different perspectives, ''zooming in and out'' or ''moving around'' the form (Galton, 1880; Seron et al., 1992; Cytowic and Eagleman, 2009). Even as viewers look right or left, ''up to'' or ''down on'' the configuration, relationships between elements within the form are reported to remain constant. For example, Jarick and colleagues describe a synesthete who imagines herself on one side of her form when she is cued by an auditory cue, and imagines herself on a different side of the form when she is triggered by a visual cue (Jarick et al., this issue, 2009). Another synesthete likens what she privately calls her ''memory maps'' to a geographical map that allows her to take in an overall view without much detail, and then zoom in on a specific enlarged region of interest (Cytowic and Eagleman, 2009).

This ability to change perspectives is often left out of theoretical frameworks, and is mentioned more often as a curiosity. However, this capacity to change points of view may serve as a critical clue. Specifically, it indicates that spatial forms do not have to be defined in coordinates fixed to the body (ego-centric coordinates), but instead consist of their own internal coordinate system, thus having the properties of an *object*. Therefore it may be useful to understand SSS as a type of *reification*, which the Oxford English Dictionary defines as ''the mental conversion of a person or abstract concept into a thing.'' (Note that reification is also used in Gestalt psychology, in which a percept contains more explicit spatial information than the sensory stimulus on which it is based, as in Kanizsa figures; Eagleman, 2001). In other words, typical synesthetes describe forms that have the properties of fixed, real objects; that is, forms are described in object-coordinates instead of ego-coordinates. One synesthete describes his weekdays as follows: ''The members are aligned in fixed positions according to each other, but their absolute locations are not determined.''

It has been previously suggested that the key to understanding spatial sequences will be to understand the spatial coordinate systems in the parietal cortex – specifically in the intraparietal sulcus (IPS) (Hubbard et al., 2005b; Tang et al., 2008). However, the reification of the sequences instead suggests a search in the parts of the brain involved in representing objects – namely, the ventral visual stream in the temporal lobes (see General discussion).

But how can this description of reified sequences encompass the variety of descriptions offered by synesthetes, some of whom describe a form fixed in front of them, some of whom describe a dynamically changing perspective on their form? To understand this, visualize your car parked right in front of you. Although you do not see it physically there (as you would with a hallucination), you will have little trouble pointing to the front and back of your imagined car, the rear wheel, the driver's side window, and so on. The car has 3D object-based coordinates in your mental space. Since the driver's side might be your preferential (default) viewpoint, you might be the type to always describe your car from that single, static point of view (which could give the impression that the car is based in ego-centric coordinates). Alternatively, you might be the type to ''move around'' your car, ''zooming in'' on details when you chose to. Some contexts might induce you to visualize yourself on the driver's side, while others will suggest the point of view from the passenger side. This description of your imagined car accords with descriptions of overlearned sequences: the forms are often imagined from a default point of view in relation to the body, but can also be experienced from different perspectives.