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The prevalence and cognitive profile of sequence-space synaesthesia

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ABSTRACT

People with sequence-space synaesthesia visualize sequential concepts such as numbers and time as an ordered pattern extending through space. Unlike other types of synaesthesia, there is no generally agreed objective method for diagnosing this variant or separating it from potentially related aspects of cognition. We use a recently-developed spatial consistency test together with a novel questionnaire on naïve samples and estimate the prevalence of sequence-space synaesthesia to be around 8.1% (Study 1) to 12.8% (Study 2). We validate our test by showing that participants classified as having sequence-space synaesthesia perform differently on lab-based tasks. They show a spatial Stroop-like interference response, they show enhanced detection of low visibility Gabor stimuli, they report more use of visual imagery, and improved memory for certain types of public events. We suggest that sequence-space synaesthesia develops from a particular neurocognitive profile linked both to greater visual imagery and enhanced visual perception.

1. Introduction

People with sequence-space synaesthesia (SSS) visualise sequential concepts such as numbers and time (e.g. years, months) as an ordered pattern (or ‘spatial form’) extending through space. These may be complex (e.g. undulating, spiraling) or simple patterns (linear); three-dimensional or two-dimensional; projected externally (e.g. as a hoop around the body) or viewed on some internal ‘inner screen’ (Eagleman, 2009; Sagiv, Simner, Collins, Butterworth, & Ward, 2006; Smilek, Callejas, Merikle, & Dixon, 2007). They can sometimes be highly prolific extending to sequenced concepts such as temperature, weight, shoe sizes, etc. (Hubbard, Ranzini, Piazza, & Dehaene, 2009). The prevalence and nature of this form of synaesthesia, and its links to cognitive ability, remains an enduring debate extending back to the Nineteenth century (e.g. Calkins, 1895; Galton, 1880a). One reason why the debate is still unresolved is that, compared to other types of synaesthesia (e.g. where the unusual experience is colour), there remains no commonly agreed diagnostic measure for SSS. In this set of studies, we take a significant step towards resolving this debate by further developing and validating a recently devised diagnostic test (Rothen, Jünemann, Mealor, Burckhardt, & Ward, 2016), and using it to assess the prevalence and cognitive profile of the (probable) synaesthetic group that pass it.

The Victorian polymath, and cousin of Charles Darwin, Francis Galton initially became interested in SSS because of its possible link to the familial inheritance of mental ability (Burbridge, 1994). Galton’s interest began when he read an obituary of a famous calculating prodigy and engineer, George Bidder (1806–1878), written by his son in which it was noted that both father and son had unusual visual imagery abilites. This included a ‘number form’ (as Galton called it) drawn by the son together with several forms depicting time (months, historical years). Through extensive surveys of other people, Galton concluded that these forms are a

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particular kind of mental imagery, created during childhood, that becomes more vivid and automatic in adulthood in those that make use of it but that disappears in those who do not (Galton, 1880b, 1880c). He estimated (without firm empirical evidence) that they were more prevalent in women and children, and he gave these estimates as 25% in school boys, 6.7% in adult females and 3.3% in males (Galton, 1880a, 1880c). Galton was unaware of the emerging literature on synaesthesia in continental Europe (Jewanski, Day, Simner, & Ward, 2011) and did not draw a link to these cases, although others soon did (e.g. Flournoy, 1893).

Other early estimates of the prevalence of SSS in the general population are 16.7% (Patrick, 1893), 11.1% (Flournoy, 1893), 12% (Calkins, 1895), and 7.3% (Phillips, 1896-97). In the contemporary literature, estimates include 14.2% (Seron, Pesenti, Noel, Deloche, & Cornet, 1992) and 12% (Sagiv et al., 2006) and 4.4% (Brang, Teuscher, Ramachandran, & Coulson, 2010). Most of these estimates tend to be based around number forms (i.e., number-space synaesthesia) although, when noted, similar prevalences tended to be found for calendars and the same individuals tend to report more than one spatial form. Typically, to meet the criteria for these studies one has to both verbally confirm the presence of a spatial form (e.g. “Do you think about numbers [letters/days/months] as being arranged in a specific pattern in space?” from Sagiv et al., 2006) and produce a drawing of it - which in some studies was also judged to be consistent over time. However, these criteria are not always as stringent as those used to diagnose other forms of synaesthesia and it is unclear how well these methods discriminate between those with true SSS and those who visualise similar representations only during testing as a result of being prompted by the experimenter, and/or rely on simple reproductions of patterns in the environment (e.g. layouts in calendars). Several studies have used Stroop-like interference tests to show that people with SSS behave differently insofar as their spatial associations are more automatic. For instance, making left/right responses to indicate the placement of a number or month on-screen is slower if the position of the stimulus is incongruent with respect to the synaesthesia (e.g. Sagiv et al., 2006; Smilek et al., 2007). These studies provide support for the authenticity of SSS (at the group level), but the interference effect at the individual level can often be small and variable making it less useful as a diagnostic measure.

For synaesthesia involving colour, the current standard is to use a computerized colour picker to select a colour for a stimulus and repeat the procedure several times so that a consistency score can be calculated (the average distance between colour selections for the same items; Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007; Rothen, Seth, Witzel, & Ward, 2013). Several tests have been developed for sequence-space synaesthesia based on the same principle, with consistency measured as the distance in some 2D or 3D space (e.g. Brang, Miller, McQuire, Ramachandran, & Coulson, 2010; Eagleman, 2009). However, these have been limited by the absence of normative cut-offs for diagnosis, and have sometimes been limited to those with particular characteristics (e.g. those who visualise their form in peripersonal space, Smilek et al., 2007). Rothen et al. (2016) attempted to address these shortcomings. They asked people with SSS to reproduce their spatial form on a 2D computer screen by making mouse clicks to indicate where each item in the sequence should be placed spatially and repeating this three times (people with 3D representations are generally able to represent them in 2D). Those without SSS were asked to think about numbers and time (days, months) spatially but were given no particular instructions as to how to do this. Using a variety of different measures of consistency Rothen et al. determined the optimal way of discriminating between the groups (based on the area bounded by their selections) and suggested a cut-off for diagnostic purposes. The current study extends this measure by creating the test online (rather than in-person) and developing a questionnaire to replace self-report. By running the measure on large samples of naive participants (i.e. not recruited on the basis of having synaesthesia) we aim to determine the prevalence and also determine whether SSS identified by these means have particular cognitive abilities in imagery, perception, or memory.

Contemporary research on SSS has provided more direct support for Galton’s (1880a) proposal that it is related to the phenomenon of mental imagery. People with SSS tend to self-report more vivid mental imagery (e.g., Price, 2009; Spiller, Jonas, Simner, & Jansari, 2015). They also perform better on cognitive tests of mental imagery ability (e.g. Brang, et al., 2010; Havlik, Carmichael, & Simner, 2015; Simner, Mayo, & Spiller, 2009; but see Rizza & Price, 2012). This superiority is linked particularly to those SS synaesthetes who mentally project sequences into external space versus the mind's eye (Havlik et al. 2015). There is also evidence that people with SSS have enhanced visual perception abilities. Ward, Rothen, Chang and Kanai (2017) administered a battery of visual perception tests to synaesthetes with grapheme-colour synaesthesia, sequence-space synaesthesia, or both. The synaesthetes as a whole were better at both colour discrimination and a measure of shape discrimination (but they did not have better visual ability in a global sense). The SSS groups, relative to controls and grapheme-colour, also had an advantage at detecting low visibility grating stimuli (Gabor patches) particularly at high spatial frequencies. The explanation for this is not fully clear, but the suggestion is that differences in perceptual sensitivity may be a prerequisite for the development of synaesthesia (Shriki, Sadeh, & Ward, 2016). Finally, SSS might be linked to memory ability. For example, spatial representations of time (years, months, days) might be used to structure memories for events – a mnemonic strategy that is not available to others. Simner, et al. (2009) found that people with SSS were better able to date news and cultural events than others, and could generate more autobiographical events given a year cue than others. In summary, whilst there is good evidence that SSS is linked to certain cognitive abilities in imagery, perception and memory, a question-mark still hangs over all these findings given that there is no agreed basis for diagnosing SSS. For instance, previous results would be confounded if it turned out to be very hard to discriminate people with SSS (who have good mental imagery) from people who have good mental imagery but don’t have SSS.

In the two studies below we use the diagnostic consistency test of Rothen et al., (2016) to determine the prevalence of SSS in individuals who were not recruited on the basis of having synaesthesia and who were not aware that the testing was about the condition. We also develop a novel questionnaire, to replace self-referral as the subjective measure. Thus, to be classed as having SSS participants must both report its subjective presence (via questionnaire) as well as meet an objective criterion (via consistency test). In Study 1 we compared the naïve sample against a set of people with probable SSS (who are active amongst the synaesthesia community). In Study 2, we recruit a new sample of naïve participants using the same diagnostic test (consistency and questionnaire) and assess them on a battery of tests that have previously been claimed to be relevant to SSS. The validity of the diagnostic test lies in