CASE STUDY

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SYNESTHETIC PERCEPTION OF TEMPERATURE AND SOUND DURING NUMERICAL PROCESSING

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SUMMARY

Background: Synesthesia is a phenomenon found in some individuals wherein a particular sensory stimulus generates a secondary response which is seemingly immaterial to the initial stimulus. This was once believed to be an extremely rare occurrence but in recent years, numerous scientific reports of various forms of synesthesia have emerged. It is most likely that a trait that is retained throughout the course of evolution provides certain benefits to the individual.
Subject PP, a 39-year-old mathematics teacher reported that temperatures and/or sounds were frequently evoked during her processing of numbers and operations. We propose that synesthesia may be employed by PP to help in the processing of numbers and mathematical computations.

Case study: PP was first interviewed by the researchers after she was discovered to be a synesthete. In our experiment, she was presented with notecards containing numbers and operations and was asked to report concurrent perceptions of temperature and sounds in each case. Composite numbers induced a higher average temperature response (7.30 +/- 1.83 units) compared to prime numbers (5.41 +/- 2.92 units; two-tailed t-test with unequal variances, $p<0.001$). Sounds, which may be mentally perceived or physically uttered, were induced more frequently by operations (26%) than by numbers (2%).

Conclusions: We conclude that the mathematical property of PP is correlated to the way her synesthetic concurrent is expressed and we propose that synesthesia may be employed by PP to help in the processing of numbers and mathematical computations.

Key words: synesthesia, numbers, temperature, sound, computation, mathematics

BACKGROUND

Synesthesia is a phenomenon whereby a person, when encountering a particular stimulus, perceives a seemingly unrelated sensation in addition to the main sensation triggered by that stimulus. (Gross, Neargarder, Caldwell-Harris & Cronin-Golomb, 2011; Pąchalska et al. 2013).

One of the most common forms of synesthesia is the grapheme-color form, where an individual perceives a specific color in response to seeing a number or letter of the alphabet. The specific color that goes with a number is usually consistent for each synesthete but may differ between one synesthete and another.

Other forms of synesthesia previously reported but are far less common include: lexical-gustatory synesthesia, where words induce taste as concurrents (Richer, Beaufils & Poirier, 2011), auditory-visual synesthesia, where sounds evoke visual effects on images seen (Fernay, Reby & Ward, 2012; Asano & Yokosawa, 2011), and tactile-emotion synesthesia, where specific textures of substances lead to the perception of distinct emotions (Ramachandran & Brang, 2008).

The most widely accepted explanation for synesthesia is that in certain people, adjacent parts of the brain show increased structural connectivity and therefore have a higher chance of cross-activation. As time goes on, these separate regions of the brain become consistently connected by the development of automatic pathways (Brang & Ramachandran, 2011, Ramachandran, 2011). Synesthesia has been observed to run in families and is believed to be at least in part genetically inherited (Tomson *et al*, 2011). Even though very early studies have suggested that synesthesia is extremely rare and occurs in one in a thousand people, it has been in recent years found to be far more common than previously thought (Ramachandran, 2011).

If indeed synesthesia is genetically inherited, how is the synesthetic trait perpetuated over evolutionary time? We believe that synesthesia is beneficial to the individual. It has been observed that some synesthetes have enhanced memory (Gross, Neargarder, Caldwell-Harris & Cronin-Golomb, 2011) and in previous studies, it has been observed that synesthetes can utilize their ability to achieve a greater level of success in mathematics (Ghirardelli, Mills, Zilioli, Bailey & Kretschmar, 2010). Our study here details a novel form of synesthesia and provides evidence that synesthesia is utilized during numerical processing.

The computation of a mathematical operation typically begins with the recognition of a shape and then equating it to a quantity, followed by the computation of those quantities in the required fashion. Although many synesthetes show responses to numbers, the neurological response associated with the perception of numbers may be different. We hypothesize that for a synesthete who responds to numbers as mathematical entities, different forms of concurrent responses would occur in response to numbers with different mathematical properties.

MATERIALS AND METHODS

Pre-experimental interview

The subject, PP, was discovered after we made an announcement during a school assembly, calling for individuals who experience seemingly unrelated perceptions upon seeing numbers or other stimuli. PP subsequently communicated about her synesthesia to a few common acquaintances and was then approached by the researchers to participate in the research.

PP is a 39-year-old, left-handed female, who teaches mathematics in a high school. She also produces quilted artwork of professional quality in her spare time and is highly involved in musical theater production and performs classical music as a hobby. PP described two relatives in her immediate family as demonstrating similar synesthetic tendencies.

PP first noticed and explored her synesthetic abilities when she was 13 years old, at 7th grade, when she encountered difficulties during a mathematics class. She noticed that sounds and temperatures were sometimes evoked whenever she worked with numbers. As she continued to explore this phenomenon, she realized that it helped her in mathematical computations. Certain numbers and operations were described as feeling “warm”. Some, on the other hand, felt “cold” while others did not produce any temperature effect. “Warm” feelings were described as being different from physical heat but instead resembling “infra-red”. Certain numbers and operations produced mental sounds as she was working with them. Examples of sounds perceived include: humming, clicking and fluttering. She would sometimes physically utter the sounds as she was sensing them in her mind. On the other hand, physical warmth and auditory sounds as stimuli do not evoke any sensation of numbers or operations. We conclude that this synesthetic ability is strictly unidirectional.

Experiment

PP was sequentially presented with 98 separate notecards. Each notecard belongs to one of the following categories of stimuli:

- Prime number: a number that is only divisible by 1 or by itself (eg. 5, 7, 29, 431)
- Composite number: a number that is divisible by numbers other than 1 or itself (eg. 4. 9, 81, 121)
- Mathematical operation (+, -, x or ÷) involving prime numbers (eg. 47-19)
- Mathematical operation (+, -, x or ÷) involving composite numbers (eg. 60÷12)

Only one-, two- and three-digit numbers were used in each of the above categories. The same numbers used as individual prime numbers were used in the prime number-type operations, and only the numbers used as individual composite numbers were used for the operations involving composite numbers. The 98 notecards were given to the subject in random order after extensive shuffling of the cards. The number or operation was displayed in large, bold, black print in the center of the notecard. At the bottom of each notecard was a number-line from 1 to 10, for the subject to circle, thereby indicating the temperature perceived. 1 was the coldest, 5 was neutral, and 10 the warmest. There was also a field to indicate a yes or no for sounds perceived, and a field available for the description of the sound perceived if any. PP viewed all 98 notecards in one sitting.

RESULTS

Of the 48 random individual numbers used as stimuli, eight were perfect squares, that is, their square roots gave a whole number (eg. 4, 9, 81, 121). These therefore form a subset of the category containing composite numbers. As seen in Figure 1, the perfect squares induced a significantly higher temperature as a concurrent, with a mean temperature of 8.50 +/- 0.57 units, compared to the forty non-perfect squares, which showed a mean temperature of 5.98 +/- 2.68 units. (two-tailed t-test with unequal variances, $p < 0.001$). Composite numbers evoked a significantly higher overall temperature, with a mean temperature of 7.30 +/- 1.83 units, compared to prime numbers, which showed a mean temperature of 5.41 +/- 2.92 units. (two-tailed t-test with unequal variances, $p < 0.001$). The 23 prime numbers given as stimuli showed the least amount of "warmth". Of all the 48 individual numbers, only one, the number "100", produced a sound, described as a "hum" by PP. None of the other individual numbers produced sounds.

Of the 50 operations used as stimuli, 26% of the operations produced sounds, as compared with only 2% of the individual numbers producing sounds (See Table 1).

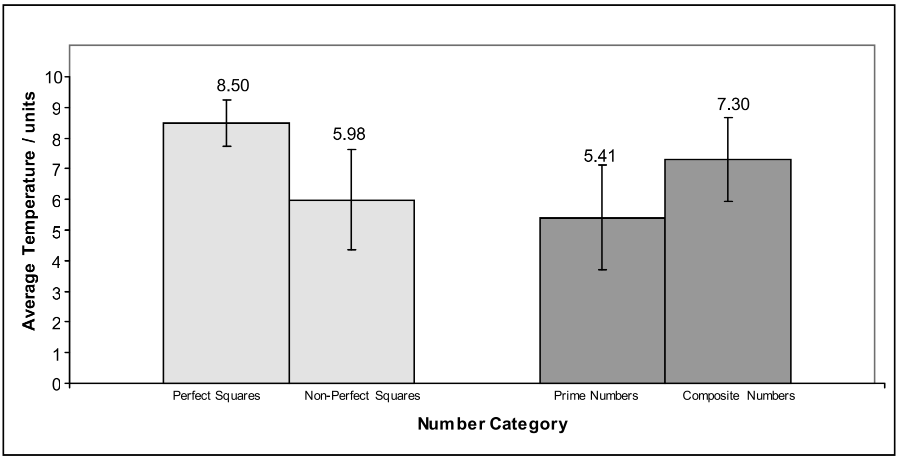

Figure 1. Comparison of PP's temperature response to various types of individual numbers. Data labels show the average temperature reported from perfect squares, non-perfect squares (including prime and composite numbers that are not perfect squares), prime numbers, and composite numbers (including perfect squares) in a single experiment. Error bars denote standard deviation in each case. A temperature unit of 5 is an indication of neutral temperature (neither warm nor cold), 10 units is the warmest and 1 the coldest.

Table 1. Results of Subject PP's concurrent responses of temperature and sounds with numbers and operations

Description of stimuli	Percentage
Operations producing sounds	26% (13 out of 50)
Individual numbers producing sounds	2% (1 out of 48)
All stimuli producing sound that also produced warmth	13% (13 out of 98)
All stimuli producing sound but no warmth	1% (1 out of 99)

Amongst all the individual numbers and operations, 13 out of 14 stimuli that produced sounds also produced warm sensations, ranging from medium high to very high temperatures. That means that only one of the 14 sound-producing stimuli produced no detectable warmth (Table 1). The sounds produced were described as "hum", "flutter" or "click". Due to the limited number of operations that produced sounds, we were unable to establish any relationship between the types of sounds and the types of operations.

DISCUSSION AND CONCLUSIONS

Prime numbers are numbers that do not comprise inherent components multiplied to each other. In PP, prime numbers did not evoke sounds or warmth with rare exceptions. On the other hand, composite numbers (including perfect squares) evoked high temperatures. Composite numbers can be seen as a result of separate numbers combined through multiplication. The mathematical property of multiplication appeared to have induced the perception of warm temperature in PP. This suggests that the temperature concurrent is somehow connected to the mathematical processing of the numbers that PP encountered. Previous studies with a color-grapheme synesthete, SE, showed that mathematical processing was sped up when the mathematical problem was presented with numbers that matched the synesthete's photism (Mills, Metzger, Foster, Valentine-Gresko & Ricketts, 2009; Ghirardelli, Mills, Zilioli, Bailey & Kretschmar, 2010). In our study, PP perceives temperature, instead of color, to form connections during numerical processing.

One of the areas of the brain that perceives warm temperature is the insula (Williams & Bargh JA, 2008). Warm sensations have also been associated with the improvement of cognitive function and mood (Lowry, Lightman & Nutt, 2008). This provides a plausible explanation for how PP, a mathematics teacher, is able to benefit from the ability to connect a mathematical property with warm temperature sensations.

PP reported perceiving mental sounds with several operation-type stimuli but no sounds with virtually all the individual numbers, except for the number 100. The trigger of auditory perception to certain mathematical operations suggests the involvement of extensive scope of brain activity and connectivity during mathematical processing, thereby engaging more parts of the brain. Indeed, previous studies have shown that synesthetes show a higher degree of structural connectivity in their brain compared to non-synesthetes (Rouw & Scholte, 2007).

Additionally, voice and utterance have long been associated in the animal kingdom as a concurrent to completing daily tasks involving effort and intent. Non-human mammals frequently use voice to intimidate, to soothe and to affirm (personal observation). A previous study showed that actions by human subjects that were supported by relevant spoken words were far more efficiently completed than when there were not (Fargier, Menoret, Boulenger, Nazir & Paulignan, 2012). It is therefore very likely that the fluttering and clicking sounds that PP perceives during mathematical computation indeed help her complete her tasks successfully. Considering that there are far more stimuli that produced warmth as well as sounds than there are stimuli that produced sounds but no warmth, we propose that in PP, sound perception is an ancillary pathway that follows after temperature perception.

Various studies done on cross-modal learning have revealed that multisensing learning has significant advantages (Shams & Seitz, 2008). Synesthetes show more exaggerated crossmodal processing (Brang and Ramachandran, 2012), and crossmodal learning has been reported to achieve better results than learning in a single modality or restricted modalities in non-synesthetes (Butler, James & James, 2011). Even though individuals are labeled as synesthetes or non-synesthetes, it is conceivable that cross-activation during the completion of challenging tasks is applicable to all individuals.

Based on previously reported studies, the left prefrontal cortex is highly involved in arithmetic computation (Davis *et al*, 2009; Kroger, Nystrom, Cohen & Johnson-Laird, 2008). In PP, we suspect that the overload of activity in the left prefrontal cortex initially resulted in the mobilization of other parts of the brain. It is possible that the cross activation of other parts of the brain helps to take the neurological processing load off the left prefrontal cortex, thereby buying time to process the problem. Brain imaging studies will be able to determine if the above cross-activation indeed occurs in subjects such as PP. At present, we are only able to conclude that mathematical processing triggers temperature and sound concurrents in PP and that these follow a fairly predictable pattern.

PP also reported during the interview that stress is an inhibitor of her synesthetic associations, and that synesthesia appears to be most prominent when she is in a relaxed mood. This agrees with the study by Nijboer & van der Stigchel (2009), where distractors were found to disrupt the synesthetic response. PP also reported that employing her synesthetic abilities consciously when engaging in art or music was a means to relieve stress. When asked, PP remarked that she would not be willing to give up her synesthetic ability if she had a choice. We conclude that synesthesia provides real benefits to this individual.

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