Introduction: is synaesthesia normal?

If a child says that the letter *G* on a toy brick has the wrong colour, it is most likely that this child is a synaesthete. In synaesthesia, which seems to be one of the most interesting and intriguing perceptual phenomena, sensory stimulation (or even imagining an inducer) can elicit an additional concurrent experience (or its mental representation). As such, synaesthetes may see sounds, smell words, taste colours, or feel tactile shapes when tasting food. These unusual experiences are involuntary, automatic, idiosyncratic, and relatively consistent over time. Some synaesthetes are surprised and disappointed when they recognize that others do not share their synaesthetic experiences.

Although it is very difficult to find two synaesthetes with identical combinations of synaesthetic associations, some general tendencies are common to all synaesthetes within a particular type of synaesthesia (e.g., linguistic-colour, music-colour, number-colour, time-space). Current research indicates remarkable similarities between synaesthesia and common cross-modal associations (e.g., Elias, Saucier, Hardie, and Sarty, 2003; Mulvenna and Walsh, 2006; Cohen Kadosh, Henik, Catena, Walsh, and Fuentes, 2009). Moreover, studies conducted among a random sample of participants revealed that synaesthetes are not easy to distinguish from non-synaesthetes (Simner, Mulvenna, *et al.*, 2006; Rogowska, 2007; Brang, Teuscher, Ramachandran, and Coulson, 2010). Synaesthesia seems to lie at the high end of a spectrum of cross-modal connections (Martino and Marks, 2001; Cohen Kadosh and Henik, 2007; Spence, 2011; Bien, ten Oever, Goebel, and Sack, 2012).

For over twenty years, scientific interest in synaesthesia has been constantly increasing. Although much research examining synaesthesia has been in the fields of neuroscience, medicine, cognitive science, linguistics, and art (Rogowska, 2011), research with reference to individual differences has been very scarce. However, this kind of research seems necessary in order to explain the nature of synaesthesia in its evolutionary context, research that may shed some light on the human development of perception, thought, and language (Ramachandran and Hubbard, 2001b).

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Research on relationships between synaesthesia and various dimensions of personality could help to resolve problems with redefining synaesthesia (Simner, 2012a, 2012b) and appointing its boundaries, as well as with examining assignation mechanisms of synaesthesia in the fields of cognitive neuroscience (e.g., Hubbard and Ramachandran, 2005; Cohen Kadosh and Walsh, 2008; Rouw, Scholte, and Colizoli, 2011) and genetics (e.g., Barnett, Finucane, *et al.*, 2008; Asher *et al.*, 2009; Tomson *et al.*, 2011). Further explanation of how synaesthesia is mediated in the brain may aid understanding of the normal processes of perceptual awareness and multisensory integration (van Leeuwen, Petersson, and Hagoort, 2010). Recent findings suggest that theories of the brain mechanisms of grapheme-colour synaesthesia need to incorporate a broader neural network underpinning multiple visual features, perceptual knowledge, and feature integration, rather than focusing solely on colour-sensitive areas (Chiou, Stelter, and Rich, 2013).

Current neuroimaging research has demonstrated that some forms of synaesthesia are caused by enhanced cross-activation between brain areas specialized for the processing of different sensory attributes. There is some evidence of increased white-matter connections among regions known to be involved in typical cross-modal processes. For example, Rouw and Scholte (2007) revealed hyperconnectivity in brain areas that mediate the type of neurological 'cross-talk' inherent in synaesthesia. Synaesthetes may display enhanced modality-specific perceptual processing, in which hyperexcitability acts as a source of noise in the visual cortex that influences the availability of the neuronal signals underlying conscious awareness of synaesthetic photisms (Terhune, Tai, Cowey, Popescu, and Cohen Kadosh, 2011).

Furthermore, Rouw and Scholte (2010) showed that distinct neural mechanisms depend on the type of synaesthesia. Projector synaesthetes' experience is related to brain areas involved in perceiving and acting in the outside world (the visual cortex, auditory cortex, motor cortex) as well as frontal brain areas, whereas associator synaesthetes' experience is related to the hippocampus and parahippocampal gyrus, known for their role in memory. Therefore, the properties of subjective experiences are in accordance with the functional properties of the mediating brain mechanisms.

The investigations of Brang and Ramachandran (2010) on the eidetic imagery of the grapheme-colour projector synaesthete seem to support the enhanced cross-activation model. Using two classic cross-modal integration tasks, Brang, Williams, and Ramachandran (2012) revealed that grapheme-colour synaesthetes exhibit enhanced cross-modal interactions between the auditory and visual modalities, suggesting that the experience of synaesthesia in one modality generalizes to enhanced cross-modal processes in other modalities. Moreover, Hänggi, Wotruba, and Jäncke's (2011) study provided evidence for global hyperconnectivity within the synaesthete's brain. These researchers suggested that synaesthetic experience might be only one phenotypic manifestation of the globally altered network architecture in grapheme-colour synaesthesia.

The similarities in the personality attributes of synaesthetes and non-synaesthetes support the theory that synaesthesia may rely on mechanisms that are common to all people (Simner, Gärtner, and Taylor, 2011). Indeed, the results of a combined psychophysics transcranial magnetic stimulation and event-related potential (ERP) study (Bien *et al.*, 2012) provided evidence that synaesthesia represents the extremity of a spectrum of normal, adaptive perceptual processes that entail close interplay between the different sensory systems. Since neurological mechanisms such as hyperconnectivity are spectral, both synaesthetes and non-synaesthetes make similar systematic cross-modal pairings in behaviour tasks (Eagleman, 2012).

On the other hand, synaesthesia may be seen as a type of neural plasticity linked to more specific cognitive processes (Ramachandran and Hubbard, 2001a). Jawer (2005) proposed the application of the term 'sensitivity' to individuals who exhibit a greater susceptibility to a range of environmental factors including allergies, migraine headache, chronic pain, and chronic fatigue, as well as a high degree of anomalous perception, such as absorption, magical thinking, transliminality, or synaesthesia. A sensitive person may be characterized as creative, sensual, imaginational, intellectual, and emotional. Moreover, ambidexterity (the ability to use either hand) was found to occur more often among persons who consider themselves sensitive.

The main aim of the present preliminary study was not to find strong evidence for some current conception of synaesthesia, but rather to explore any new directions for further research. Here, synaesthesia was investigated in a wide context of individual differences in such dimensions as personality, temperament, intelligence, emotionality, gender, body lateralization, and cognitive capacities (e.g., attention, memory, imagery, colour perception). The other aspect of individual differences refers to the synaesthesia phenomenon. Synaesthetes may differ from each other in various features, including the following:

(1) The quantitative indices of synaesthesia:
   - range of associations within particular categories of synaesthetic inducers (e.g., complete range of letters within the alphabet vs. selected letters)
   - range of synaesthetic categories (e.g., grapheme-colour, music-colour, time-space)

- number of modalities involved within synaesthetic experiences (e.g., one modality in grapheme-colour synaesthesia vs. four modalities when music induces smell, taste, and touch sensations).

(2) The qualitative indices of synaesthesia:
- level of cognitive processes: sensory in lower synaesthetes (e.g., pain-colour) vs. semantic in higher synaesthetes (e.g., time-space)
- place of both inducer and concurrent experience occurrence (i.e., internal – as a mental representation – vs. external – as a sensory experience)
- feedback experiences (i.e., unidirectional inducer-concurrent experiences vs. bidirectional experiences).

Thus, the description of a subjective synaesthetic experience (Rogowska, 2011) may comprise various categories and types of a particular form of synaesthesia, such as intramodal, intermodal, bimodal, multimodal, analytic, synthetic, partial, comprehensive, sensory, semantic, perceptual, conceptual, internal (associators), external (projectors), unidirectional, and bidirectional. Idiosyncratic configuration of these types within one synaesthete might decide the place of an individual case on the weak–strong dimension of a synaesthesia trait.

Synaesthesia has usually been examined as a dichotomous variable, and in numerous studies, the strongest cases are compared with samples of ‘non-synaesthetes’. Although this procedure is standard and ‘safe’, it does not seem to reflect the phenomenology of synaesthetic experiences and the existence of a wide set of individual differences between synaesthetes. Therefore, Chapter 1 of the present study examines whether linguistic-colour synaesthesia is a continuous and normal trait. A sample of 161 Polish undergraduates (including 82 women – 51%) between 20 and 44 years of age (22.67 ± 2.40) completed the Linguistic-Colour Association Test (L-CAT) – for full details on the participants, see Appendix A. The test consisted of 135 items in 10 categories: Colours, Fruits, Verbs, Adjectives, Months and Seasons, Days, Forenames, Pseudowords, Numbers, and Alphabet. The values of colours used in the test were transformed from the RGB (red, green, blue) model into the CIELab colour space before calculating the test–retest Euclidean distance. In this study, synaesthesia was regarded as a continuous variable according to two indices: consistency over time (C) and range of linguistic-colour association (R). The L-CAT scales revealed a normal distribution in C and a mixture of normal distributions in R. Exploratory factor analysis (EFA) extracted one factor for consistency of linguistic-colour associations, a finding that may point to a common basis for synaesthetic-abstract and common-concrete associations. The expectation-maximization (EM) clustering algorithm revealed two clusters of complete and selective associators.

The results of this investigation suggest that linguistic-colour synaesthesia is a strong abstract form of association on the concrete–abstract and weak–strong dimensions.

The range of linguistic-colour associations, as objective and quantitative indices of the strength of synaesthesia, was reconciled with subjective self-report qualitative methods, as described in Chapter 2. These studies also explored the relationships between linguistic-colour synaesthesia and self-related sensing, body lateralization, and gender. An objective method of examining the consistency of the linguistic-colour associations of the L-CAT was combined with participants' self-reports in the Synaesthetic Association Questionnaire (SAQ). Among 141 participants, 19 (13%) were arbitrarily recognized as linguistic-colour synaesthetes on the basis of both self-report and test–retest consistency methods. However, weaker types of synaesthesia may occur much more frequently, following a normal distribution. Although linguistic-colour synaesthesia was found to be associated neither with gender nor with body-sidedness, an interaction effect was revealed between gender and sidedness. Linguistic-colour synaesthesia seems to occur more frequently in one-sided women and lateralized men. Moreover, linguistic-colour synaesthetes reported poorer touch perception and more frequent migraine experience than non-synaesthetes. The results of these studies were explained in light of the compensatory hypothesis, with a possible contribution of the somatosensory cortex to the development of language skills.

Chapter 3 of the present study concerns the investigation of the relationship between linguistic-colour synaesthesia and cognitive capacities such as visual colour discrimination, visual and verbal memory, general selective attention (the d2 Test of Attention), and self-reported imagination. Sample A of the university student participants, including 11 linguistic-colour synaesthetes and 63 non-synaesthetes, completed a battery of tests and questionnaires assessing the strength of linguistic-colour synaesthesia (L-CAT), colour discrimination (the Visual Colour Discrimination Test), visual memory (the Benton Visual Retention Test), verbal memory (the Word List Recall Test), general selective attention (the d2 Test of Attention), and self-reported imagination (the Imagination Inventory).

Linguistic-colour synaesthetes outperformed non-synaesthetes in colour perception, verbal memory, general selective attention, and self-reported imagination. Moreover, synaesthetes demonstrated heightened engagement in experiences, which was significantly correlated to the strength of linguistic-colour associations. The pattern of these correlations was similar to the connection between absorption and linguistic-colour synaesthesia discussed in Chapter 4. These findings seem to

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suggest that synaesthetic mental representation requires increased cognitive resources of attention, imagination, and memory. However, the results of a cluster analysis indicated that individual differences in these cognitive abilities also exist among synaesthetes. The fundamental question regarding the explanation of synaesthetic mechanisms remains: are enhanced cognitive abilities the basis of the emergence of synaesthesia, or, alternatively, is synaesthesia an opportunity that facilitates the development of cognitive skills?

The relationships involved in linguistic-colour synaesthesia and individual differences in absorption, creative thinking, types of mind, and emotional and fluid intelligence were the main subject of the study described in Chapter 4. Sample A of 79 undergraduate participants, including 57 women (72%), completed the L-CAT to assess the consistency of synaesthetic associations over time, the Test for Creative Thinking-Drawing Production (TCT-DP), the Tellegen Absorption Scale (TAS), the Types of Mind Scale (TMS), Raven's Standard Progressive Matrices (SPM) as an assessment of fluid intelligence, and the Popular Emotional Intelligence Questionnaire (PEIQ). Linguistic-colour synaesthesia was found to be associated with both absorption and scale acceptation of emotion in the PEIQ. A second-order relation was also found by EFA. In the hierarchical model of *thinking*, the linguistic-colour associations were related to *openness to unusual experiences*, together with absorption and creativity, whereas in the hierarchical model of *association*, linguistic-colour associations were related to *internal associations*, together with absorption, fluid intelligence, and global types of mind. However, the study constitutes a preliminary analysis that needs to be supported by studies on much larger and more random samples of participants.

Chapter 5 covers a study examining whether synaesthesia is related to traits of temperament and personality. A total of 79 participants of Sample B, including eight linguistic-colour synaesthetes, completed the L-CAT, Big Five personality inventory (the Neuroticism Extraversion Openness Five-Factor Inventory (NEO-FFI)), and three temperament questionnaires: the Emotionality-Activity-Sociability Temperament Survey (EAS-TS), the Formal Characteristics of Behaviour – Temperament Inventory (FCB-TI), and the Pavlovian Temperament Survey (PTS). Participants of Sample A, including 11 linguistic-colour synaesthetes and 68 non-synaesthetes, completed the L-CAT and three-dimensional personality assessment, using the Eysenck Personality Questionnaire – Revised (EPQ-R). Synaesthetes differed from non-synaesthetes in higher conscientiousness and extraversion, and also in the balance of their nervous system processes. Synaesthetes showed a higher tendency to a predominance of strength of inhibition over excitation. Conversely, in non-synaesthetes, excitation dominated over inhibition. The L-CAT was correlated with extraversion and agreeableness in the NEO-FFI, with the Lie Scale of the EPQ-R, with anger from the EAS-TS in synaesthetes, and with sensory sensitivity in non-synaesthetes. Partial least-squares (PLS) regression was performed on the Sample B synaesthetes' results. This analysis showed that four higher-order latent variables (emotionality, arousability, sociability, and disinhibition) in the model accounted for 87% of the variance of the L-CAT and explained 99% of the variance of individual differences in personality and temperament.

It is important to note that there are some limitationss to the present set of studies. The main limitation is small sample size, so conclusions from the present study are not very strong. Among 141 students participating in the synaesthesia assessment, only 19 were considered to be linguistic-colour synaesthetes. Nevertheless, only half of the total sample (approximately 70 participants, including either 8 or 11 synaesthetes) were involved in studies described in Chapters 3, 4, and 5, which concerned relationships between linguistic-colour synaesthesia and individual differences in cognitive and personality dimensions. Although standard statistical methods were used, with an adequate level of significance for the small sample size, we should regard the results with caution. Thus, replication of the present research with a more random and much larger sample size seems necessary for further examination of the tendencies found in the present investigations. However, the results of the present study seem to be strongly related to one specific assessment, and this is a second limitation of the study. Thus, it is most likely that other research using alternative synaesthesia tests, as well as other methods of assessing personality, intelligence, and cognitive dimensions, may give different outcomes from the results found here. The third limitation of the study is that all of the participants were White and Polish (see Appendix A for more details). If linguistic-colour synaesthesia depends strongly on language, race, culture, and social context, the present results cannot be generalized for people from other countries and cultures. Future comparative studies conducted across several countries and cultural groups may resolve these issues. Finally, the present study relates to linguistic types of synaesthesia. The other types and kinds of synaesthesia (e.g., music-colour, touch-smell, ordinal-linguistic personification, mirror-touch, number-form) may involve distinct relationships with either personality or other dimensions of individual differences.

When we consider the limitations described above together, it seems appropriate to regard the present study as a preliminary case study, in which the same participants were involved in multiple psychological measures. This deep view of linguistic-colour synaesthesia in a wide context of other human traits seems be a unique opportunity to formulate general rules for the origination of both cross-modal and intramodal associations. Because association seems to be the most basic element of the thinking process, this kind of knowledge may shed light on the development of human intelligence and creativity. On the other hand, studying synaesthesia may help to explain cognitive disorders such as schizophrenia, unusual states of consciousness (e.g., aura vision, out-of-body experiences, mystical states), savant skills, and autism. Therefore, cross-sectional research seems necessary in the future.

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1 Exploring the structure and distribution of linguistic-colour associations in the concrete–abstract and strong–weak dimensions

1.1 Relationship between synaesthesia and common association

Synaesthesia is described in the scientific literature as an unusual, bizarre, and rare phenomenon (Hochel and Milán, 2008). Some researchers, however, express doubts about the mysterious nature of synaesthesia, observing a number of similarities between synaesthesia and common cross-modal associations (e.g., Elias *et al.*, 2003; Mulvenna and Walsh, 2006; Cohen Kadosh, Henik, Catena *et al.*, 2009). Indeed, several studies indicate that both synaesthetes and non-synaesthetes can associate high-pitched sounds with bright colours, and low tones with dark colours (Marks, 1989; Ward, Huckstep, and Tsakanikos, 2006; Spence, 2011). In addition, many non-synaesthetes can link spatial forms with days of the week or months in a similar manner to time-space synaesthetes (Makioka, 2009; Brang *et al.*, 2010).

The tendency of synaesthetes to connect colours with language (i.e., letters of the alphabet, numbers, words) is similar to that of non-synaesthetes (Hubbard, 1996; Simner *et al.*, 2005; Cohen Kadosh, Henik, and Walsh, 2007). A recent study (Brang, Rouw, Ramachandran, and Coulson, 2011) revealed that more similarly shaped graphemes correspond with more similar synaesthetic colours, stronger effects observed in individuals and more intense synaesthetic experiences (projector synaesthetes). These results support the cascaded cross-tuning (CCT) model of synaesthesia, implicate early perceptual mechanisms as driving factors in the elicitation of synaesthetic hues, and further highlight the relationship between the conceptual and perceptual factors of synaesthesia.

Furthermore, a recent study by Watson, Akins, and Enns (2012) revealed that the shape, frequency, and ordinality of individual letters have a secondary influence on synaesthetic colour assignments. This suggests that synaesthetic associations are acquired alongside learning the alphabet, with associations involving letter shapes, ordinality, and frequency made independently and idiosyncratically. Because these mappings of the structure of similarities between letters and colours are similar to those in numerous other cognitive and perceptual domains, the implication is that synaesthetic associations operate on principles common to many areas of human cognition.

Perhaps there is a common mechanism that accounts for cross-modal associations in both synaesthetes and non-synaesthetes. Some researchers propose that synaesthesia lies at the high end of a spectrum of cross-modal connections (Martino and Marks, 2001; Cohen Kadosh and Henik, 2007; Spence, 2011; Bien *et al.*, 2012). According to Martino and Marks (2001), weak synaesthesia represents common cross-modal associations that are dependent on individual experience and implicit knowledge about interactions between concrete objects (Marks, Hammeal, and Bornstein, 1987). Perceptual knowledge about objects and events is represented in terms of locations in a multidimensional and multimodal space. For example, large musical instruments (e.g., bassoon, cello, double bass) produce lower and milder sounds than smaller instruments (e.g., flute, clarinet, violin). Verbal processes thus access this graded perceptual knowledge, permitting an interpretation of synaesthetic metaphors according to the rules of cross-modal perception. Strong synaesthesia (Martino and Marks, 2001), also known as idiopathic, constitutional (Grossenbacher, 1997), or developmental synaesthesia (Harrison and Baron-Cohen, 1997), refers to idiosyncratically more abstract associations such as musical notation-colour (Ward, Tsakanikos, and Bray, 2006), time-space (Brang *et al.*, 2010), and ordinal-linguistic personification (Amin *et al.*, 2011; Simner *et al.*, 2011).

In this context, the problem of the distinction between synaesthesia and other forms of associations arises. What are the borders and the nature of the relationship between synaesthesia and common associations? Apart from being an inducer in the abstract–concrete dimension, a genetic basis seems to be another origin of synaesthesia and the acquisition of common and cross-modal associations. The rationale behind the genetic origin theory originates from some evidence that synaesthesia may run in families (Bailey and Johnson, 1997; Barnett, Finucane, *et al.*, 2008; Tomson *et al.*, 2011), and that the proportion of female to male synaesthetes reveals that more females than males report synaesthetic experiences (Baron-Cohen, Burt, Smith-Laittan, Harrison, and Bolton, 1996; Rich, Bradshaw, and Mattingley, 2005).

Although, at present, progress in the exploration of the genetic basis of synaesthesia can be noted (Bargary and Mitchell, 2008; Brang and Ramachandran, 2011), some reports appear to be inconsistent in their support for a strong genetic basis of synaesthesia. For example, Smilek