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# Modality and Variability of Synesthetic Experience

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In synesthesia, stimulation of one sensory or cognitive pathway leads to additional, involuntary experiences in a second sensory or cognitive pathway. We here review previous surveys on this neurologically based phenomenon and report the results of 63 synesthetes who completed our Internet and paper questionnaire on synesthesia. In addition to asking for personal data and information on the participant's synesthesia, the questionnaire focused on the components of the inducer that elicit or modulate synesthesia. Synesthesia was most often developmental (92%) and of the grapheme–color type (86%). Sixty-two percent of the participants perceived time-related words in a spatial configuration. Music–color synesthesia was common (41%), and synesthesia for natural and artificial sounds (33%) was higher than in previous estimates. Eighty-one percent of participants experienced more than one form of synesthesia. Multimodal synesthesia, in which inducer and concurrent belong to 2 different sensory modalities, occurred in 92% of the participants. Overall, auditory stimuli were most often reported as inducers, and visual concurrents were most common. Modulations of the synesthetic experiences such as changes of the concurrent color, expansion within the same or to a different sensory modality, or reduction of the number of inducers over time were reported by 17% of participants. This challenges the presumed consistency of synesthesia and the adequacy of the test–retest consistency score still most commonly used to assess the veracity of reported synesthesia. Implications of the high prevalence of cross-modal synesthesia and the variability of synesthesia are discussed.

A "feminine and old narrow-minded '6'" has nothing in common with a "strong and dynamic '9'" (Participant 7). Whereas few non-synesthetes associate numbers with personality, people with grapheme–personification synesthesia would not be surprised by such attributions. Synesthesia is a neurologically based phenomenon in which a stimulus in one sensory modality triggers an additional experience in another. In effective inventory of diagnostic criteria, Price and Mentzoni (2008) summarized the following hallmarks of developmental synesthesia: It tends to arise spontaneously in early childhood, it is induced involuntarily, it is vivid and personally important, and its precise details vary idiosyncratically, even if its broader nature often has some similarity across synesthetes. Synesthesia appears quite stable over time, and synesthetes are typically surprised to discover that other people do not share their experiences.

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A number of surveys conducted to explore this fascinating condition made important contributions to the study of synesthesia, although consensus has not been reached for every aspect. Studies vary widely in the prevalence estimates, ranging from 1 in 4 to 1 in 100,000 (for a summary, see Simner et al., 2006b) and often disagree on which form of synesthesia is the most common. Although grapheme–color (GC) synesthesia is the most common type according to some authors (Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996; Rich, Bradshaw, & Mattingley, 2005), others report similarly high prevalence rates for number forms (Sagiv, Simner, Collins, Butterworth, & Ward, 2006) or spatially arranged time units (Barnett et al., 2008; Simner et al., 2006b). Several factors may be responsible for inconsistent prevalence rates. First, the different studies are based on different, sometimes small sample sizes (for a summary, see Table 1) and apply different inclusion criteria. For example, Baron-Cohen et al. (1996) excluded participants who reported only day–color synesthesia, and Simner et al. (2006b) excluded reports of letters and numbers having spatial orientations, gender, and personality traits. In contrast, Sagiv et al. (2006) purposely focused on number–form synesthesia. Second, the recent wave of interest in synesthesia shapes its taxonomy (Emrich, Schneider, & Zedler, 2002) and increases synesthetes' awareness of their additional perceptions; both factors may contribute to the variance of prevalence rates. Third, studies vary in their recruitment procedures (Table 1). Whereas earlier studies recruited participants through advertisements in local newspapers (Baron-Cohen et al., 1996; Rich et al., 2005) or from university communities and museum visitors (Simner et al., 2006b), more recent surveys have used a university Web site (Sagiv et al., 2006) or both Internet and newspaper advertisements (Barnett et al., 2008). All together, these factors may influence the estimated prevalence rate of synesthesia and its subtypes.

Compared with more traditional sources, Internet surveys on synesthesia have several advantages. First, due to both the simplicity of Internet searches and the fact that synesthetes are normally interested in their particular condition, as evidenced by the abundance of Internet forums, blogs, and associations of synesthetes, they allow the collection of a large amount of responses in a short time. The recent proliferation of Internet-based synesthesia questionnaires and publication of data based on large samples of synesthetes

**TABLE 1.** Prevalence Data From Surveys of Synesthesia

| | N | Female :male | Synesthesia prevalence (%) | Main synesthesia type prevalence (%) | Method of recruitment and data collection |
|---|---|---|---|---|---|
| Baron-Cohen et al. (1996) | 22 S, 6 NS | 6.3:1 | 0.05 | 100 GC<br>40.9 MC<br>13.6 SC | Newspaper advertisement |
| Rich et al. (2005) | 192 S, 50 NS | 6.1:1 | 0.05 | 87 GC<br>~25 MC and SC | Newspaper advertisement |
| Sagiv et al. (2006) | 114 S, 311 NS | 3.5:1 | | 87.7 GC<br>80 NF<br>14.2 LG | Internet |
| Simner et al. (2006b): 2 studies | 22 S, 478 NS<br>13 S, 1,177 NS | 1.1:1<br>0.9:1 | 4.4<br>1.1 | 72 GC<br>9 PC<br>4 PS | University students; museum visitors |
| Barnett et al. (2008a) | 92 S, 310 NS | 6:1 | 23 | 45.3 GC<br>42 SP<br>18.7 MC<br>4.7 SC | Internet and newspaper advertisement |

Note. *GC = grapheme–color synesthesia; LG = lexical–gustatory synesthesia; MC = music–color synesthesia; NF = number–form synesthesia; NS = non-synesthetes; PC = people–color synesthesia; PS = people–smell synesthesia; S = synesthetes; SC = sound–color synesthesia; SP = spatial patterns for time units.*

(Tomson et al., 2011) support the notion that the Internet is a valuable instrument to collect information on this population; for example, see the questionnaires of Waterloo University (http://www.bu.edu/dbin/synesthesia), the UK Synaesthesia Association (http://www.uksynaesthesia.com/questionnaire.htm), and the Synaesthesia Battery by Eagleman et al. (2007). Second, participants can comfortably respond at home at a time of their choosing and do not need to contact or visit a research center, a time-consuming procedure that may be discouraging. Third, people may find it easier to respond openly to Internet than to paper questionnaires or interviewers, because of the Internet's relative anonymity. Although anonymity might have a drawback in terms of honesty, it is relevant for sensitive topics, including drug use, medical conditions, and synesthesia. Several synesthetes report that they have been ridiculed for their experiences and therefore tend to keep them to themselves (Emrich et al., 2002; Price & Mentzoni, 2008; Ramachandran & Hubbard, 2001). However, it is worth noting that Internet research also has some shortcomings. For example, the ease of completing Internet data reports might affect the depth of the data collection. Participants might be less careful in completing a questionnaire on the Internet compared with a laboratory setting because they may feel that they are not supervised. In addition, this sampling method can make prevalence difficult to estimate; to track and estimate the number of visitors to our Web site, we used an Internet statistical instrument (http://www.google.com/analytics) in the present study.

We here report data collected by means of an Internet questionnaire uploaded at Düsseldorf University and a paper questionnaire completed by synesthetes who were recruited through an advertisement on a synesthesia-related Web site. Our questionnaires aimed at characterizing the synesthetic associations and specifically the components of the inducers that elicit or modulate synesthesia. Studies on GC synesthesia[1] have already shown that a variety of stimulus parameters affect the induced synesthetic experiences ("concurrents"). Systematic relationships between the colors generated by words and those generated by graphemes within the word have been reported (Ward, Simner, & Auyeung, 2005). Simner, Glover, and Mowat (2006a) proposed a process of competition between constituent graphemes, in which stressed graphemes and initial graphemes are disproportionately weighted. Asking whether homophones (*sun/son*) or words with similar initial phonemes but different initial letters (*fish/photograph*) would evoke concurrents reflecting semantics, phonemes, or graphemes, Baron-Cohen, Harrison, Goldstein, and Wyke (1993) found that in their nine synesthetes it was the initial letter that determined the word color. A marked impact of first or dominant phonemes or graphemes on the concurrent color has been described in other studies (Baron-Cohen et al., 1993; Rich et al., 2005). Moreover, the font has been suggested to influence the intensity of coloring (e.g., saturation; Witthoft & Winawer, 2006). Whereas these studies focused on the influence of a word's visual characteristics on the synesthetic percept, others have suggested that phonemes may determine the concurrent colors (Galton, 1883; Harrison & Baron-Cohen, 1995; Paulesu et al., 1995; Aleman, Rutten, Sitskoorn, Dautzenberg, & Ramsey, 2001). Moreover, case studies have shown that the concept or categorization of a stimulus can trigger synesthesia (Dixon, Smilek, Duffy, Zanna, & Merikle, 2006; Myles, Dixon, Smilek, & Merikle, 2003). We here aim to shed more light on the triggers of the forms of synesthesia that are present in our sample by inspecting the inducers' features and modality and identifying components that are responsible for giving rise to and modulating concurrent experiences.

We also aim to explore two issues that have not been extensively addressed in previous surveys. The first is the prevalence of cross-modal versus intramodal synesthesia, the second the variability of synesthesia over time. When forms of synesthesia different from GC synesthesia are considered, it appears that the prevalence of cross-modal synesthesia ranges from 23% (Barnett et al., 2008) to 54% (Baron-Cohen et al., 1996) of participants. However, because the percentage of participants with synesthesia for spoken words, letters, or digits has not been specified, an exact estimate of the occurrence of cross-modal synesthesia is not possible. With regard to the variability of the synesthetic experiences, the use of a retest to verify synesthesia indicates that its stability over time is generally taken to be an important hallmark. However, contrary evidence comes from Rich et al. (2005), who reported that the intensity of synesthesia can decrease with age, and from Hubbard, Manohar, and Ramachandran (2006), who described a GC synesthete whose color experiences changed with the contrast of a digit, a finding that was confirmed by Eagleman et al. (2007) in one of 12 GC synesthetes. Moreover, an analysis of the subjective locus of synesthetic colors conducted by Edquist, Rich, Brinkman, and Mattingley (2006) suggested both that the reliability of self-reports of synesthetes may be questionable and that the subjective experiences of synesthesia are highly variable. We therefore explicitly asked participants to describe any variations they experienced in their synesthesia in the period of time preceding the compilation of the questionnaire.

## EXPERIMENT

### METHODS

A German and a translated Dutch version of our questionnaire were used. The German version appeared on the Internet; the Dutch one was presented on paper. The Internet questionnaire appeared in the institute's section of the Düsseldorf Heinrich Heine University Web site from March to August 2007. The paper questionnaire was completed by synesthetes recruited through an advertisement on a synesthesia-related Web site from June to December 2007. After a brief introduction to synesthesia, participants were asked to describe their forms of synesthesia in a free text field. Both the German and Dutch questionnaires included multiple-choice and open questions (see the Appendix). The first part of the questionnaire focused on characteristics of the respondents' synesthesia, their family members, spoken languages, medical history, active or passive forms of artistic occupation, and hobbies. Because the Internet survey's advantageous anonymity would suffer if participants identified themselves, we did not require respondents to enter their names or contact addresses. Although using a data code for each participant is a option, this method was not applied in the present survey. The second part was divided into sections pertaining to different forms of synesthesia. Here, a total of 159 stimuli including words, letters, numbers (word and digit forms), punctuation marks, time-related words, color names, and nonwords were presented. In addition, participants could provide their own examples of inducers and concurrents. To describe concurrents, they could choose from 276 coded colors (RGB system) on the Internet questionnaire and report details in writing on both the Internet and paper questionnaires. Thirty questionnaires were completed online, and 33 questionnaires were returned by mail. Twenty-seven people from the Dutch sample took part in a surprise retest on 20 graphemes 8 to 45 months (mean 28 months) after the initial study, yielding to an average consistency score of 91.2%. Because no marked differences emerged between the German and the Dutch questionnaire, data were collapsed for analysis.

### RESULTS

A total of 63 participants completed our questionnaire. Responses to multiple-choice questions were ordered by item, and the resulting frequencies were analyzed. For the sake of clarity, results are presented in subsections. After describing the participants' demographic characteristics, we report the prevalence and features of the different forms of synesthesia in the sample. We then address the characteristics of the concurrents and the changes that affect both inducers and concurrents over time.

#### *Demographic Characteristics of Participants*

Considering that the number of visitors at our university Web site was about 1,500 during the same period, the prevalence rate would amount to 2%. However, the participants may have found the Web site when searching the Internet for new information on synesthesia rather than accessing it for other reasons. In this not improbable case, the number of respondents would be unrelated to the number of visitors. No prevalence estimate is possible from the Dutch sample.

The sample's sex ratio was female biased (3.5:1 female:male). Fifty-seven percent of participants reported no academic degree. The average age of the Dutch participants was 29 years ($SD$ = 10); age data for the German participants were not available. However, it seems unlikely that the German sample consisted mainly of students, because 42% of these participants reported that they discovered themselves to be synesthetes after the age of 25 (Figure 1), an uncommon age for university students. One person did not report gender and educational data. For all but one participant the native language was either German or Dutch. Except for three participants, all indicated that they spoke a second language fluently or pretty well, and 57% spoke a third language but not fluently. The second and third languages were based on the Latin alphabet, except in four cases where the Cyrillic alphabet was used. Eighty-five percent of participants with synesthesia for words experienced it also in the foreign languages. This included the four respondents who had learned to read Cyrillic letters. Most participants reported experiencing synesthesia on a daily basis (81%) and having had synesthesia all their lives (90%). The remaining participants reported the first synesthetic experience to occur at a specific age: two at the age of 6 or 7, one at the age of 12, and one at the age of 25; one person did not respond to this item. Ninety-two percent of the participants learned that they were synesthetes after reaching the age of 14, and 81% rated their synesthesia in the medium to strong range of intensity (between 5 and 10 on a 0–10 scale).

Thirty-five percent of participants reported having at least one first-degree relative with synesthesia, and as many participants did not know or did not answer. In the majority of the cases, the participant's and the relative's synesthesia were of the same type, and in half of the cases the mentioned first-degree relative was the mother. Only one participant reported that a second-degree relative experienced a form of synesthesia similar to his, and one synesthete who was part of a multiple birth reported that the siblings did not experience synesthesia.

Nine percent of the participants and 2 of the 21 family members reported to be synesthetes had an artistic profession. Questions about creative or artistic inclinations revealed that most respondents were artistically active (68%) or enjoyed visual art (62%). Interest in reading, photography, and languages was frequently reported. Seventy-eight percent of participants judged synesthesia to be an advantage in creative jobs and in memorizing, learning, or calculating. Whereas the rate of reported benefits in learning was related to the presence of GC synesthesia ($p$ = .001, Fisher's exact test), the strength of synesthesia (categorized as intensity greater or less than 5) did not appear to play a role in advantages in learning ($p$ = .10, Fisher's exact test). Consistent with data on the reported advantages of having synesthesia, participants frequently described themselves as skilled at painting, learning, speaking foreign languages, and memorizing things; 19% reported having a photographic memory. Poor abilities were reported in mathematics and in tasks involving sustained concentration, spatial imagination, and spatial perception.

Responses to a multiple-choice question indicated that 60% of participants assumed that synesthesia has a genetic basis. Although 71% of participants could not think of anything in their past that may have brought on synesthesia, others suggested that their suffering from headache, depression, or epilepsy influenced the development of synesthesia. In six cases synesthesia was reported to be initiated by a stimulus such as a colored dictionary, a musical clock, or a TV schedule with colored weekdays. In one case, the color coding for numbers in electronics was mentioned as the origin of his synesthesia; this participant received his first set of resistors with color bands related to numbers for his sixth birthday.

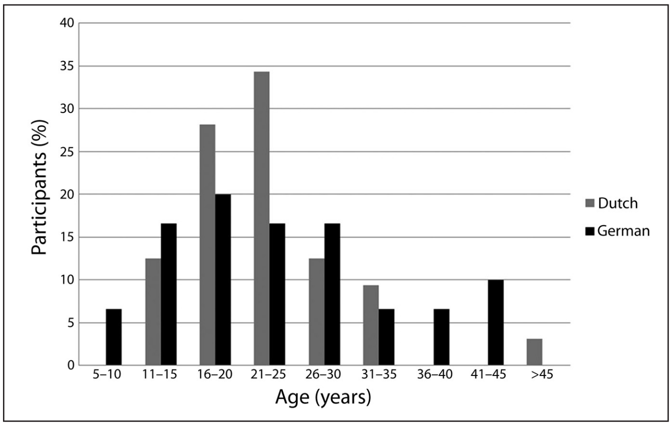


**FIGURE 1.** Age at which participants in the German ($N$ = 31) and the Dutch samples ($N$ = 32) learned they were synesthetes

The prevalence of migraine in the sample, which consisted largely of women, was comparable to that found in the female German and Dutch population (30% vs. 32.5%; Stovner, Zwart, Hagen, Terwindt, & Pascual, 2006). Seventeen percent of participants reported depression. This self-reported rate is not significantly different from the depression prevalence rate in primary care in Germany (12%; Wittchen & Pittrow, 2002) ($\chi^2$ = 1.31; $p$ = .25). Seven participants reported occasional use of drugs (e.g., LSD, cannabis).

*Types of Synesthesia*

The most common form of synesthesia among our participants was GC synesthesia, with synesthesia for digits being more common (86%) than synesthesia for letters (79%) and words (81%) (Figure 2). Only two participants reported personality and gender as concurrents for digits. Synesthesia for time units was the second most frequently reported type (62%), followed by synesthesia for music (41%) and for natural or artificial noises (33%). Synesthesia for pain (14%),

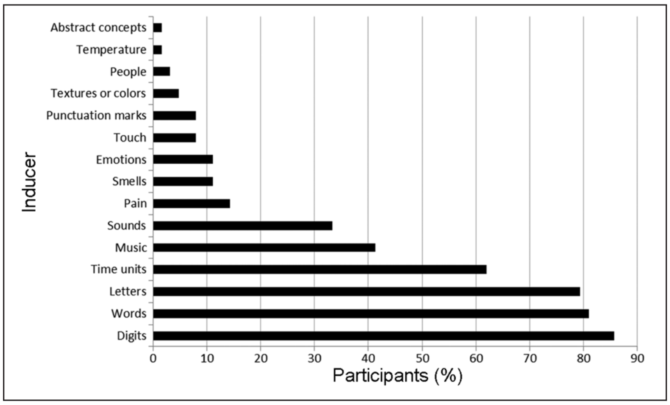


**FIGURE 2.** Frequency rates for different forms of synesthesia in the sample ($N$ = 63), grouped by type of inducer

smell (11%), and emotions (11%) was less common. Synesthesia for touch or punctuation marks was rarer still (8%) but more common than synesthesia for textures or colors, people, temperature, and abstract concepts.

Ninety percent of our participants were self-reported associators who claimed that synesthesia occurred in their "mind's eye." The remaining participants described themselves as projectors who perceived the concurrents in the outside world, in the vicinity of the inducer, or on their own body (Dixon, Smilek, & Merikle, 2004). Eighty-one percent of participants had multiple synesthesias. Nineteen percent of the participants reported synesthesia from a single type of inducer, 32% responded to two, and the remaining 49% listed three to six types. The prevalence of the types of synesthesia grouped by number of inducers is showed in Figure 3.

### *GRAPHEME–COLOR SYNESTHESIA*

Sixty-five percent of participants reported synesthesia for letters, words, and digits. As shown in Figure 4, the synesthetic perception for participants with GC synesthesia depended on the modality in which the inducer was presented. Only heard (i.e., auditorily presented) stimuli elicited synesthesia in up to 18% of participants with GC synesthesia. All other participants either needed to read the inducers (up to 22%) or responded to both formats (up to 76%). Whereas 59% experienced color concurrents for heard and read words, 18% reported it for read-only and 22% for heard-only words. Subtle differences in these proportions occurred for graphemes or phonemes, words, and digits. Words more often than either letters or numbers elicited synesthetic experiences in either heard or read format but not both. The words' concurrents were influenced by their first letter and their strongest vowel in 29% and 26% of the participants with lexical synesthesia, respectively. In another 33% of cases, the concurrent reflected a combination of the synesthetic colors elicited from each composing letter. In only 6% of cases did the words' meaning affect the synesthetic perception. Hearing or reading color words (e.g., *red*) elicited a color concurrent in 89% of the participants, and in most cases the concurrent was reported to be congruent with the one indicated by the word. These data agree with the concurrent color trends participants reported for the color names from the word list. Seventy-four percent of participants with synesthesia for words and letters also perceived colored concurrents for the nonwords in the list, indicating that a meaningless series of graphemes or phonemes often suffices to elicit synesthesia and implying that synesthesia was linked to early, presemantic stages of word processing.

Analogously, color concurrents of multiple digits (e.g., *1324*) in most cases were determined by a combination of the constituents' colors (68%) or by the first digit's color (13%). Variations in hue or lightness elicited by variations in font (e.g., italic, handwriting) and font size were reported by 16% of the participants.

### *SYNESTHESIA FOR SPOKEN LANGUAGE, MUSIC, AND SOUNDS*

Forty percent of the participants had synesthesia for at least two of the three categories phonemes, heard music, and sounds. Seventy-five percent of these participants also responded to the written format. Approximately 90% of GC synesthetes reported colors in response to spoken letters, digits, or words. Forty percent of the participants with synesthesia for spoken words reported that voice pitch or features such as accent and prosody influenced the synesthetic color. However, volume and speed of talking played

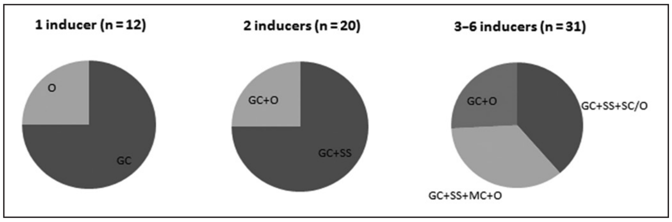


**FIGURE 3.** Prevalence of combinations of synesthesia types in the sample, grouped by number of inducers. GC = grapheme–color synesthesia; MC = music–color synesthesia; O = other forms of synesthesia; SC = sound–color synesthesia; SS = sequence–space synesthesia

a role for only a few participants. Whereas the speakers' emotional inflection could affect the concurrent color, only two participants reported that their own mood altered the colors.

Forty-one percent of our participants had synesthesia for music. Heard music stimuli elicited a concurrent in many more cases than visual music stimuli ($p$ = .01, Fisher's exact test) (Figure 4). Seventy-five percent of the participants with synesthesia for music perceived colors exclusively when listening to notes being played. Synesthesia triggered by listening to musical stimuli showed that tone pitch and type of instrument affected the concurrent's color in 40% and 26% of participants, respectively. Thirty-three percent of participants reported color concurrents for artificial environmental sounds (e.g., "the doorbell sounds yellow") or animate and inanimate natural sounds; "yellow bird song" and "turquoise sounds made by leaves in the wind" exemplify these associations. One participant experienced pain or gooseflesh when hearing particular sounds (e.g., *kri*). In our sample, the stimulation of the auditory modality induced synesthetic experiences as frequently as the stimulation of the visual modality.

#### *SYNESTHESIA FOR TIME UNITS*

A total of 62% of our participants perceived a spatial pattern while reading or hearing time-related words (e.g., "the year is oval" or "the week is rectangular"). Of these, 93% reported the spatial pattern in addition to a color. For 67% of participants with synesthesia for time units, thinking of time units was sufficient to elicit a spatial pattern. As shown by the prevalent combinations of synesthesia types in Figure 3, spatial sequence synesthesia accompanied GC synesthesia in the large majority of participants who reported two or more types of inducer.

#### *SYNESTHESIA FOR PAIN AND TOUCH*

Fourteen percent of participants experienced synesthesia for pain and 8% for touch. Not all forms of pain and touch elicited synesthetic perceptions, and the reported inducers were specific: Bodily aches (e.g., headache, bellyache), a cut, or being stroked are examples of painful inducers. The concurrents presented as colors and forms or patterns: a bright yellow sting, a violet headache, or the image of a fragmented glass panel induced by a finger cut. One person reported pain as a concurrent, which was evoked by auditory stimulation, namely brief sounds.

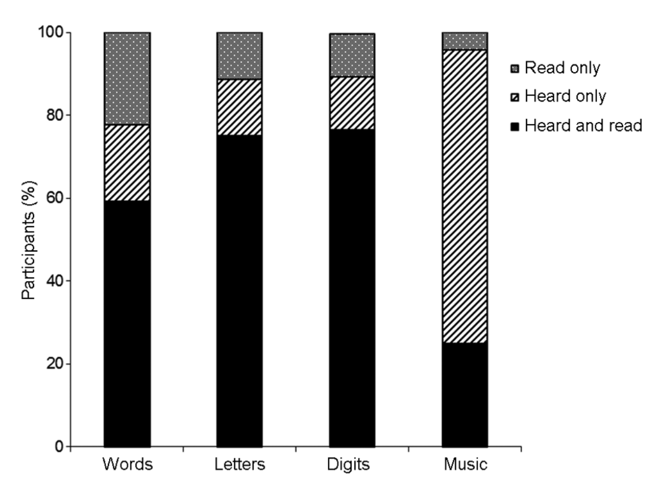


**FIGURE 4.** Participants reporting grapheme–color or music–color synesthesia. Although both could be elicited by heard or read stimuli, in many cases the concurrents depended on the sensory modality in which the inducer was presented

### *Types and Characteristics of Concurrent Perceptions*

Color was the most frequent concurrent for our sample (97%), followed by spatial configurations (62%; Figure 5). Reports of colored concurrents showed that in most cases the color appeared instantly (89%) and was static (73%). The remainder reported that the color moved in a specific direction (16%); in only one case did it move randomly. According to 71% of participants, the synesthetic color did not interfere with the physical color of the inducer (e.g., black ink color for graphemes). The two hues were distinguishable because the concurrent's color was brighter, more intense, dazzling, or transparent. The visual modality clearly dominated the concurrents, whereas auditory concurrents were extremely rare.

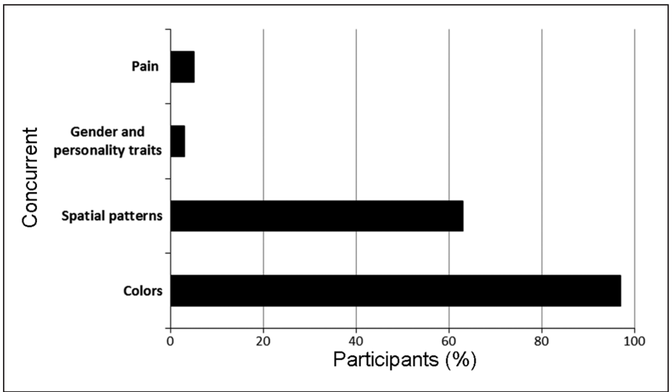


**FIGURE 5.** Frequency rates for the different types of concurrents in the sample. Except one participant who reported tones as only concurrent, all participants perceived synesthetic colors in addition to at least one other concurrent such as spatial patterns, gender, personality traits, taste, temperature, or movement

*Cross-Modal and Intramodal Synesthesia*

Ninety-two percent of participants had at least one form of cross-modal synesthesia. In most cases (89%), auditory inducers evoked visual concurrents. The reverse coupling—a visual stimulus eliciting auditory concurrents—was never reported. For 19% of the participants with cross-modal synesthesia, the inducer was somatosensory and gave rise to visual concurrents in all cases but two, in which the concurrent was auditory. The reverse association between auditory inducers and somatosensory concurrents occurred in two cases as well. In one case auditory stimuli induced gustatory concurrents. Associations between olfactory inducers and visual concurrents were reported by 11% of the participants, and visual inducers and gustatory concurrents were associated in only one case. Seventy-six percent described intramodal synesthesia. In all those cases the inducers were written-only graphemes, words, digits, or musical notes, and they evoked color concurrents. A summary of the frequency-weighted cross-modal and intramodal associations is given in Figure 6.

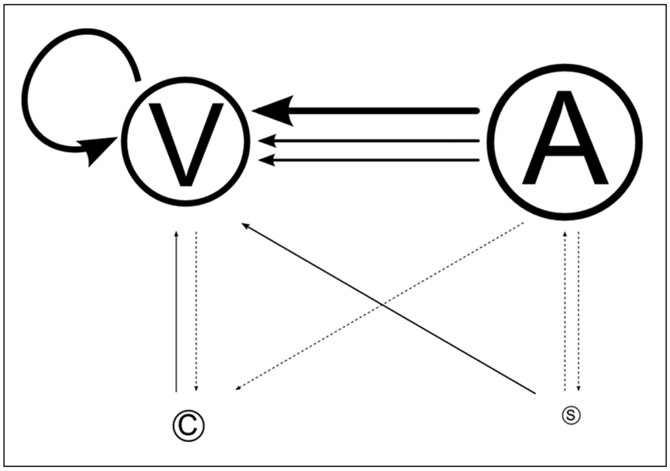


**FIGURE 6.** Schematic representation of the intramodal and cross-modal associations in the sample. Circle size represents frequency of inducer modality. Arrows indicate the direction of the association, thickness reflects their prevalence; dotted lines indicate a prevalence of less than 10%. Connections between the auditory and visual modalities represent phoneme–color, heard music–color, and sound–color synesthesia (top to bottom). The visual format is not only the most common for concurrents but also the only one that itself engenders visual concurrents, color being the most common concurrent submodality. A = auditory; C = chemosensory; S = somatosensory; V = visual

*Characteristics of Synesthesia and Development Over Time*

For 33% of participants the intensity changed over time, so that the synesthetic perception had become stronger (28% of these participants) or weaker (28%) or that the participants had become more aware of it (14%). In 9% of these cases, the color elicited by a specific inducer changed over time. Although the type of inducer remained constant during life for most participants (82%), some participants (5%) reported an expansion within the same sensory modality. Further variations such as spreading to a different sensory modality (3%) or narrowing of the number of inducers eliciting synesthesia (3%) were reported. Another 6% of participants reported changes over time that they did not specify.

We asked the participants whether they could voluntarily control their synesthesia and either induce or stop the concurrent's occurrence. Thirty-three percent of the participants indicated that they could smother or ignore as well as evoke the concurrent at will, whereas the remaining participants could not control it completely or only with much effort. Although this finding is inconsistent with the noted automaticity of synesthesia, 52% of these participants were confirmed synesthetes according to their consistency score (91%). Also, 59% of the participants reported that attention affected their synesthetic perceptions. Other factors that altered the synesthetic experience included level of concentration, fatigue, insufficient sleep, fever, emotional involvement, and some substances (coffee, alcohol, and medications). Whereas caffeine and medications enhanced synesthesia, fatigue could either strengthen or weaken the sensations.

## DISCUSSION

Self-reports of 63 synesthetes yielded the following main conclusions: Heard- and read-GC synesthesia was the most commonly reported type, followed by synesthesia for spatial patterns for time units and for music and sounds. The inducer's modality was important in the majority of cases, and its particular features rather than its meaning determined the precise appearance of the concurrent. A substantial proportion of respondents found that their concurrent experiences had changed over time or were influenced by factors including attention, fatigue, fever, emotion, and substances such as caffeine.

*Demographic Characteristics*

In agreement with previous studies, we found a marked preponderance of females in our sample (Barnett et al., 2008; Baron-Cohen et al., 1996; Rich et al., 2005). This bias may reflect a genetically based difference, but a higher propensity of women to respond to this type of questionnaire may certainly contribute. Indeed, the two studies that sampled university students and museum visitors without prior regard to their synesthetic status found essentially no gender difference (1.1:1 and 0.9:1, respectively; Simner et al., 2006b). Compared with the estimated prevalence of synesthesia, participants often reported that they had synesthetes among their family members, who in most cases was the mother and had the same type of synesthesia as the participant. Although this lends further support to a genetic influence, associations with specific childhood memories were mentioned by six participants. Reminiscent of a synesthete who learned her colors from a toy (Witthoft & Winawer, 2006), they corroborate the assumption that particular synesthetic associations are acquired through experience. Possibly, the particular inducer–concurrent pairings reflect early learning experiences in those who have a genetic predisposition for synesthesia (Rich et al., 2005; Simner, Harrold, Creed, Monro, & Foulkes, 2009).

Our participants' involvement in artistic and creative activities is consistent with the finding that about one fourth of the synesthetes are artists or have artistic professions (Cytowic, 1989, 26%; Domino, 1989, 23%; Rich et al., 2005, 24%). Interestingly, Rader and Tellegen (1987) reported a relationship between vividness of visual images associated with sound and a tendency to enjoy and become involved in imaginative experiences. Moreover, results from self-report scales and behavioral testing show that synesthetes report more vivid imagery than controls (Barnett & Newell, 2007) and have stronger imagery skills at least for a grapheme-based task (Spiller & Jansari, 2008). Creativity mirrors the ability to form new combinations between things; in this, synesthetes might profit from their richer perceptual repertoire.

*Prevalence of Types of Synesthesia*

Although results from our study mostly agree with previous surveys based on larger samples, we also observed some striking differences in prevalence rates. GC synesthesia was most often reported (86%): Our prevalence estimate for this form of synesthesia lies between that of Baron-Cohen et al. (100%; 1996) and that of Barnett et al. (45.3%; 2008) (Table 1). Unlike Baron-Cohen et al., we found color synesthesia for digits to be more frequent than synesthesia for letters and words. In addition, our data showed that the majority of participants responded to both auditory and visually presented graphemes and words. Although there is some evidence for phoneme–color synesthesia being rarer than GC synesthesia, with prevalence estimates of 7.4% versus 63.5% (Sean Day, http://home.comcast.net/~sean.day/html/types.htm), to our knowledge no survey has reported on it. The 41% prevalence of color–music synesthesia found by Baron-Cohen et al. coincides with ours, and both are higher than the 25% and 18.7% reported by Rich et al. (2005) and Barnett et al. (2008), respectively. However, the 33% of our sample who reported colored concurrents for natural and artificial sounds is higher than in other studies. Baron-Cohen et al. reported only 13% for auditory stimuli that excluded words and music, and Rich et al. found a rate of about 25% for music–sound synesthesia in their 192 synesthetes. Moreover, unlike Barnett et al., who found that 42% of their 92 synesthetes described spatial patterns for time-related words, we found 62% in our sample. The discrepancies probably reflect differences in sample size and composition as well as in participant recruitment, and data collection methods—whether examples are presented, how questions are formulated—may play an additional role.

Rates of self-reported associators and projectors, 90% and 10% in our sample, are more biased toward associators than those reported by Barnett et al. (2008; 72% vs. 12%). Dixon et al. (2004) reported closer fractions (58% vs. 41%) for a sample of 12 participants, and Van Leeuwen, Petersson, and Hagoort (2010) classified their 21 GC synesthetes into six associators, seven projectors who experienced the color overlaid onto the graphemes, and eight "mental screen" projectors who experience the color in external space but not in the vicinity of the graphemes. If the last group is counted among the associators (Ward et al., 2007), this group comes up to 67%. All together, these data account for a higher prevalence of associators among synesthetes.

### *Inducer Modality and Properties*

According to our synesthetes' self-reports, the modality of the inducer (seen vs. heard) appeared to carry greater weight in music–color synesthesia than in synesthesia for words, letters, and digits (Figure 4). Seventy-one of the participants with synesthesia for music perceived colors exclusively when listening to notes being played. People with synesthesia for words, letters, or digits most often responded to both written and spoken stimuli (70%), whereas the heard-only and read-only fractions come in at up to 15%. Unfortunately, we do not know whether any, or how many, of our participants with heard-only music synesthesia could read music, thus limiting our conclusions about their inducer modality.

If a person cannot read music, the notes do not correspond to tones and may thus fail to elicit concurrents. Likewise, an illiterate synesthete would probably not associate heard words and phonemes with written letters and thus experience color only when hearing or speaking language. Also, reading music is often taught later than reading text, so that written notes may be learned too late to acquire the automaticity of synesthetic concurrents. This could be tested among music students who learned to read notes at a very young age. In the present sample, reported examples of musical inducers were exclusively instruments or tone pitch. Not even a participant with absolute pitch named a note, suggesting that notes as such, and the concept of tones they represent, are comparatively unlikely inducers. Accordingly, De Thornley Head (2006) showed that synesthetes consistently matched color with pitch, without interference from note name information, even when the name was misleading.

If the age at which the child is exposed to the inducers is important in developmental synesthesia, the format in which the inducers are more commonly encountered in early life would take priority over the one acquired later. Like notes, letters of languages such as Greek or Arabic would be less likely to induce colors in people who, like German pupils, learn Roman letters in kindergarten or elementary school and foreign script in their teens, if at all. Although this might increase the probability of heard-only grapheme synesthesia for foreign languages, their phonemes and the visual forms of their characters could still elicit concurrents as long as they resemble those of the familiar languages (Mills et al., 2002; Witthoft & Winawer, 2006). By analogy, written notations would need to be learned at a time in life when the new format can easily be linked to a previously established auditory one. One would expect corresponding phonemes and graphemes to induce the same concurrents in those cases. Note that this was true in our sample for all participants with heard-and-read synesthesia for words, letters, and digits.

An alternative explanation for these results is that the visual, acoustic, and semantic levels of representation are intercalated in the synesthetic process independent of the age at which the person learns to read and write. That the sound of a letter is accompanied by its visual and semantic representation in eliciting a concurrent is evidenced by Bargary, Barnett, Mitchell, and Newell (2009) for phoneme–color synesthesia and by Ward and Simner (2003) for phoneme–taste synesthesia. In addition, Dixon, Smilek, and Merikle (2000) demonstrated that activating the concept of a digit by mental calculation was sufficient to induce the color relative to this digit in a participant with color synesthesia for written digits. Together, these results hint at a connection between an inducer's visual, acoustic, and semantic level of representation. Further experimental testing and broader surveys are needed to shed more light on these issues.

### *Modalities of Synesthesia*

We found that intramodal visual and cross-modal auditory–visual synesthesia were most prevalent. Whereas dense connections between visual areas might explain the high prevalence of intramodal visual synesthesia, it is more difficult to explain the high frequency of auditory–visual or somatic–visual synesthesia. Our findings suggest high unidirectional disinhibition and cross-modal connection between the auditory and visual area and between the somatosensory and the visual area. Consistently, there is evidence that more than half of visually responsive neurons also respond to auditory or somatosensory stimuli (Macaluso, 2006). Projections from auditory parabelt regions to both V1 and V2 and direct inputs to peripheral V1 from the primary auditory cortex (Rockland & Ojima, 2003; Falchier, Clavagnier, Barone, & Kennedy, 2002) and somatosensory input to auditory association cortex have been found in the monkey (Schroeder et al., 2001). The high prevalence of specific cross-modal synesthetic associations might therefore suggest that the synesthetic associations track normal cross-modal anatomic pathways. However, it is unclear why the visual modality appears to be the preferred site for concurrents in both cross-modal and intramodal synesthesia. Possibly, the high differentiation of the visual system in neural subsystems specialized in the processing of color, form, orientation, and movement offers a broader range of possibilities for cross-submodal as well as for cross-modal connectivity compared with other sensory systems.

### *Development and Stability of Synesthesia*

Both the concurrents' occurrence and their intensity may vary across time. Our self-report data confirm previous findings (Rich et al., 2005) and show that even the type of inducer or the concurrent colors' intensity was subject to change (11% and 33%, respectively). Accordingly, in their 12-month longitudinal test on children, Simner et al. (2009) showed that synesthetes acquired on average 6.4 new GC associations, and they proposed that a linear acquisition would predict that synesthetes will have acquired all 36 GC associations only by 10 or 11 years. These data not only account for changes in synesthesia over time but also show that changes might be detected only in specific time windows in the life of a synesthete. Although our data on variability of synesthesia are not based on a follow-up, it is unlikely that changes may be detected by means of a consistency test few months apart from the first test. Further specification of the age at which participants remember the changes to occur might help define the time window to look at when addressing variability issues in synesthesia.

Moreover, some substances and mental and physical states (e.g., caffeine, fatigue) reportedly affect the perception of a concurrent. Such variations are incompatible with the notion that synesthesia is completely stable over time and raise questions about the adequacy of the consistency test. This test assesses the genuineness of self-reported synesthesia through the comparison of concurrents listed at two or more points separated in time by weeks or months and is often regarded as the gold standard that distinguishes synesthetes from non-synesthetes. However, the consistency estimate for synesthesia is commonly lower than 100% and ranges between 73% and 100%. Rich et al. (2005) suggested that changes of the perceived color over time may explain the imperfect consistency. Surely, variations of the color concurrents across consistency test and retest would not necessarily rule out that synesthesia is authentic (Ward & Mattingley, 2006), and a synesthete failing the test–retest could still pass a perceptual reality test (Proulx & Stoerig, 2006). Although high levels of consistency are desirable for particular studies, adhering to a strict consistency criterion may exclude authentic synesthetes from one's sample. Moreover, participants with implicit synesthesia, who report strong GC association but score in a medium range in the consistency test (Steven, Hansen, & Blakemore, 2004), will probably be neglected.

To preserve the anonymity of our respondents, we did not collect long-term consistency data for the larger part of our sample. Nevertheless, several observations support the veracity of the respondents' self-reports. First, participants not only reported the forms of their synesthesia but also indicated the synesthetic sensations evoked by items listed in the questionnaire and reported specific examples of inducers and concurrents of their own. Second, all participants completed the questionnaire. Given that this took time and dedication, people with no authentic synesthesia probably would have left it uncompleted. Finally, color concurrents, if not chosen from the color palette, were reported as detailed descriptions of complex colors. This agrees with what is typical of synesthetes' color reports. Rather than using labels such as "blue" or "brown," they denote their color concurrents as "strong medium blue" (for number *5,* Participant 8), "inconspicuous weak brown" (for the word *pensioner,* Participant 2), or "dark purple with yellow blobs" (for the word *January,* Participant 2).

### *Conclusions*

Our self-report data showed that the modality of the inducer plays an important role in eliciting a concurrent and that the latter depends predominantly on specific visual or auditory features rather than the semantic value of the inducer. Cases linking the origin of synesthesia to childhood experiences indicate that environmental factors might combine with a genetic predisposition in the induction of synesthesia. The finding that synesthetes can ignore or attenuate their synesthetic perception challenges the presumed automaticity of synesthesia and calls for objective evidence. The prevalence of auditory stimuli as inducers and of visual qualia as concurrents appears interesting in light of the ontology and the neural basis of synesthesia and may further inform neurocognitive models on synesthesia. Finally, although they are based on time point self-reports, our data question the stability of synesthesia over time, an issue from which future research may benefit. The exclusion of low-consistency synesthetes may result in a generalization of findings to a population that is actually more varied.

### NOTES

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1. Grapheme–color synesthesia includes grapheme, phoneme, and lexical color synesthesia unless otherwise specified.

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## *APPENDIX. QUESTIONNAIRE ITEMS FOCUSING ON THE CHARACTERISTICS OF THE RESPONDENT'S SYNESTHESIA*

Please describe your synaesthesia: Please include all the things that can generate your synaesthesia and briefly describe your synaesthetic perception/s.

Do these things always elicit synaesthesia?

❑ Yes ❑ No, not always (please describe when)

Does the same synaesthetic trigger always induce the same experiences?

❑ Yes ❑ No (please describe)

How intense is your current synaesthetic experience on a scale from 1 (very weak) to 10 (strong)?

1 2 3 4 5 6 7 8 9 10

Are your synaesthetic experiences in the form of a perception (namely, you *actually see* colors while for ex. reading letters or hearing sounds) or do these impressions appear more associative in your "interior eye"?

❑ perception ❑ interior eye ❑ both

Are your synaesthetic perceptions accompanied by special textures?

❑ No ❑ Yes, namely . . .

Do your synaesthetic colors look like the colors of objects?

❑ Yes ❑ No, they are different because . . .

When did your synaesthesia occur the first time?

❑ I had it all my life ❑ At the age of . . .

At what age did you learn that your sensory experience was actually synaesthesia?

Has the intensity of your synaesthetic experiences changed over time?

- ❑ No
- ❑ it has become stronger
- ❑ it has become weaker
- ❑ other changes (Please describe)

Has the range of stimuli which *trigger* your synaesthesia (noises, tastes, etc.) changed over time?

- ❑ no change
- ❑ it has become smaller
- ❑ it has become larger within a same sensory modality (for ex. heard words ➙ heard words and music)
- ❑ it has spread to other senses (for ex., noises ➙ noises and tastes)
- ❑ other changes (please describe)

If you have different forms of synaesthesia, how do you experience them?

- ❑ simultaneously
- ❑ separated
- ❑ involuntarily varying
- ❑ I can decide how

Can you control your synaesthesia (can you stop or voluntarily elicit the synaesthetic perception)?

❑ no ❑ yes ❑ other (please describe)