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Seeing sounds and tingling tongues: Qualia in synaesthesia and sensory substitution

Abstract In this paper we wish to bring together two seemingly independent areas of research: synaesthesia and sensory substitution. Synaesthesia refers to a rare condition where a sensory stimulus elicits not only the sensation that stimulus evokes in its own modality, but an additional one; a synaesthete may thus hear the word "Monday", and, in addition to hearing it, have a concurrent visual experience of a red color. Sensory substitution, in contrast, attempts to substitute a sensory modality that a person has lost by transforming the information it provided so that it can be accessed through another, intact sensory modality. To make visual information accessible to a blind person, for example, data taken by a camera would be transformed into tactile or auditory information. What do synaesthesia and sensory substitution have in common? Research in both of these areas contributes to our understanding both of cross-modal cooperation and of sensory sensations or qualia, asking under what circumstances these can arise in a modality that is not stimulated. Synaesthesia reveals that this "sensory cross-activation" is possible, and sensory substitution research hopes to induce it. In this article, we will review briefly the literature on synaesthesia, and discuss the issue of qualia for this domain of research. We will then address the evidence for synaesthesia and visual qualia in the blind, and the research on sensory substitution, to finally ask whether sensory substitution may induce a 'synthetic' form of synaesthesia by taking advantage of the nervous system's capacity for generating visual images in the absence of retinal input.

Key words Synaesthesia, sensory substitution, qualia, auditory, visual, tactile, crossmodal.

Qualia in synaesthesia

The term 'synaesthesia' derives from the Greek 'syn' (together) and 'aisthesis' (perception), and originally means 'perceiving together'. When we see a dog and hear him barking, we thus perceive his image together with the sounds he emits, combining inputs from two sensory modalities. In its more restricted, now common meaning, however, synaesthesia refers to a condition where a physical stimulus induces a sensation not only in the modality whose receptors it stimulates, but in an additional one as well. The stimulus that triggers the synaesthetic sensation is the *inducer*, and the extra sensations are called *concurrents.*

Although Marks (1975) reviewed reports that perhaps date back to Pythagorus and Aristotle, and Larner (2006) has uncovered evidence of a possible report of synaesthesia from the seventeenth century, many reviews date the first investigations of synaesthesia back to Galton (1880). Galton focused his investigation on the relation between numbers and mental imagery, and described correspondence from individuals who see black numbers (inducers) as colored (concurrents), such as "3" looks yellow and "4" looks red. Although this color-grapheme form of synaesthesia, where a number or letter is seen in a particular color, is probably the most common form of synaesthesia, many other types exist. Marks (1975) focused his review on colored-hearing synaesthesia, where sounds induce the experience of color (see also Harrison & Baron-Cohen, 1995). Associations between flavors and shapes (Cytowic, 1993; Ramachandran & Hubbard, 2003), between hearing and taste sensations (Beeli, Esslen & Jäncke, 2005), and between emotions and colors have all been documented in the literature, and it seems that almost any type of combination of inducer and concurrent is possible. Note however that even synaesthetes associating the same modalities do not have the same concurrent sensations evoked by the same stimulus. One synaesthete may describe a "3"as transparent yellow, another as reddish brown, showing that the associations are both idiosyncratic and very specific.

What are the concurrent sensations like? Do they resemble those that non-synaesthetes perceive when the appropriate modality is directly stimulated? Would the word 'hog', printed in oxblood red letters, evoke the same sensation in a non-synaesthete as the same word, only printed in black, evokes in a color-grapheme synaesthete who reports that 'hog' induces the experience of oxblood red? According to a distinction drawn by Dixon, Smilek and Merikle (2004), only a *projector* synaesthete experiences the concurrent color as if the grapheme was overlaid by that color. The word 'hog' would thus appear as if a somewhat transparent version of the same word was laid on top of the printed one, still allowing the synaesthete to see the black print of the grapheme. Although one would thus see both the color of the print and the concurrent one, the latter too would appear as actually present in the external world.

In contrast, an *associator* synaesthete describes her color experience as having an internal quality. Dixon et al. (2004) draw an analogy to a normal individual's experience of seeing a black-and-white photograph of a stop sign. Although one does not see the color red in the picture, one may have an internal experience of red evoked by the picture. Thus these synaesthetes have no external experience of the concurrent color, but rather see the word in the color of its print. Whether this division between types of synaesthesia runs on a continuum, such as the ability to produce vivid visual imagery does, is an open question for future research. For example, it might be the case that projector synaesthetes are in fact just experiencing a stronger version of the induced color experience than the associator synaesthetes, which leads to a specific percept of color, and consequences associated with that percept (Dixon et al. 2004). The distinction between projector and associator synaesthetes might thus correspond to the "higher" and "lower" manifestations of synaesthesia described by Ramachandran and Hubbard (2001b). Similarly, the experience of a color induced by a sound, such as a musical note, may vary between individuals. Unlike colored-grapheme synaesthesia, there is no external, visual object to be colored in colored hearing. What is the quality of the visual experience of color that is induced by sound? Ward, Huckstep and Tsakanikos (2006; see also Zigler, 1930) describe some synaesthetes who experience visual shapes that are colored according to the sound they hear, and others that just experience a general color sensation, perhaps similar to the associator synaesthetes described by Dixon et al. (2004). It thus appears as if the perceptual density of the concurrent qualia may differ. Nonetheless the concurrent qualia are commonly of the kind that non-synaesthetes perceive when the concurrent modality is directly stimulated.

On the automaticity and perceptual reality of the synaesthetic experience

Research on synaesthesia has evolved from merely describing cases, as with Galton (1880), to testing the consistency, perceptual reality and automaticity of the synaesthetic experience. This shift has taken place recently, although tests of consistency of one's synaesthetic experience through test-retest means was already used by Starr (1893). Taken up again by Baron-Cohen, Wyke, & Binnie (1987), and recently revised by Asher, Aitken, Farooqi, Kurmani, and Baron-Cohen (2006), this 'Test of Genuineness' distinguishes synaesthetes from their non-synaesthetic brethren by asking both for associations with inducers, and finding identical responses that average from 70 to 90% across time delays ranging from months to years, and without prior warning of testing, in the synaesthetes. This is about two- or threefold the average replication rate seen in non-synaesthetes, and shows that associations are commonly very stable over time. However, as pointed out by Ward and Mattingly (2006), 'genuineness' of synaesthesia would not need to be reflected in such stability of associations: A person who at different points in time experiences different extra sensations in response to the same stimulus would still be a synaesthete, if of an 'inconstant concurrent' kind.

Such a person would fail the test-retest 'test', but could still pass the test devised to tackle the perceptual reality of the synaesthetic experience. Ramachandran and Hubbard (2001a) first demonstrated that synaesthetic colors resulted in perceptual grouping in two grapheme-color synaesthetes, which suggested that the experience of the concurrent colors resembled that of real grouping by color. They also found that when the inducing letter or number was placed far in the synaesthete's peripheral vision, the synaesthetes had no experience of color even though they could still recognize the identity of the inducer. The experience of color thus was not just a metaphor or a memorized association, but rather quite similar to normal color perception. Later work by Palmeri, Blake, Marois, Flanery and Whetsell (2002) found that the synaesthetically-experienced colors could affect the speed by which one visually searched for a grapheme. Although visual search for a digital clock style *2* among *5*s is normally inefficient, and takes longer with each distractor *5* added to the display, a synaesthete with different colors induced by the *2s* and *5s* could find the target more rapidly than a non-synaesthete. The number *2* would pop-out of the display and be found quickly, much as one could easily find a singular red flower in a field of green grass (cf. Treisman & Gelade, 1980). There is even evidence that synaesthetically-induced colors perceptually group with real-colored items, suggesting that synaesthetic colors are indeed experienced in the external world, much as actual printed colors are (Kim, Blake & Palmeri, 2006).

Synaesthetic sensations can thus be experienced consistently and color one's perception of the world. But how automatic is the experience of color that is induced by a grapheme? Recent research has approached this question in a variety of ways. The most popular is to use a Stroop interference paradigm, where the synaesthetic experience of color, if automatic, can help or hinder one's performance on a task. For example, Palmeri et al. (2002) presented words to a synaesthete that either appeared in the color that the words evoked for that synaesthete or in a different color. The task was to name the color of the letters on the screen, not the induced concurrent color. For congruent trials, the synaesthete saw the word "moose" with pink letters, which is the same color that the word "moose" induces in the synaesthete. For incongruent trials, the word would be shown in a different color, such as green. The synaesthete was significantly slower to name the color of the letters on incongruent trials than on congruent trials, just as non-synaesthetes are slower to read color words that are printed in colors different from the one the color names (cf. Stroop, 1935). Just like the printed colors, those evoked by the words were automatically induced and conflicted with the perception of the actual color of the letters in the synaesthete. Others have demonstrated Stroop-like interference for colored-hearing synaesthetes as well (Ward et al., 2006). Note, however, that the automaticity these findings suggest does not imply that the concurrent sensation is evoked pre-attentively; after all, the tasks used all require attention being deployed to the target words or graphemes (Sagiv, Heer, & Robertson, 2006).

All of the above studies are concerned with what is called *developmental* synaesthesia (Grossenbacher & Lovelace, 2001). Developmental synaesthesia may have a genetic basis, as indicated by studies on its incidence in families, and especially monozygotic twins (Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996), as well as a possible difference in its prevalence among males and females, with a higher prevalence in females (0.087% of females and 0.014% of males; Rich, Bradshaw & Mattingley, 2005). Developmental synaesthetes do not remember ever not having had their concurrent sensations.

Synaesthesia arising from visual deprivation

However, synaesthesia can also be acquired. Hallucinogenic drugs often induce synaesthesia, and, of even greater interest in our context, sensory deprivation can have a similar effect. Sensory deprivation, whether temporary, as through blindfolding of normal sighted volunteers, or permanent, as through sensory deafferentation, very often induces hallucinations in the modality deprived of its input (Merabet et al., 2004; Bonnet, 1760). In addition to such release phenomena, Armel and Ramachandran (1999) described a patient who gradually lost his sight due to degeneration of the retina. A couple of years after becoming totally blind, he began to have visual experiences induced by tactile sensations. Blind synaesthetes have also been studied by Jacobs, Karpik, Bozian, and Gothgen (1981) and Steven and Blakemore (2004), although the latter authors stress that their six subjects had developmental synaesthesia that persisted despite continued blindness. In all cases, colors were the concurrent sensations which were most often elicited by letter phonemes, numbers, and days of the week as well as months; only one also had colors for Braille. Descriptions of colored hearing in the blind go back to the late 19th century (Galton, 1880; Phillipe, 1893; Starr, 1893), and continued through the peak period of interest in synaesthesia in the 1920s (e.g. Wheeler and Cutsforth, 1921; Cutsforth, 1924; Voss, 1929). Even if some of these cases may have been of the developmental kind, sensory deprivation is likely to have contributed. If so, synaesthetes should be much more common among the blind, deaf, or numb, than among the sighted, hearing, and feeling. Indeed, in the latter the overall prevalence is estimated at a variable but rather low 0.02 to 5% of the population (Baron-Cohen et al., 1996; Rich et al., 2005, Simner et al., in press), while Phillipe (1893) estimated its incidence among the blind as ~33%!

Reports of synaesthesia in patients with central rather than peripheral neuropathology are rarer. Vike, Jabbari & Maitland (1984) reported that a patient with a large tumor in the left medial temporal lobe experienced visual phenomena in response to sound. The induced visual experience was only in response to sounds presented to the left ear, and only appeared in the left eye, both ipsilateral to the tumor. When the tumor was removed operatively, the synaesthetic experiences ended.

Acquired synaesthesia in patients with brain tumors and in the blind arose as a result of different types of nervous system modification: one central and one peripheral. However the hypothesis in both cases was that sensory deafferentation could have possibly resulted in the experience of synaesthesia. In the case of the blind patient, the lack of visual input that might normally override auditory-related response in visual cortex could have given rise to the visual experience of sounds. In the case of the patient with a brain tumor, who had an intact visual pathway, the tumor may have blocked some non-critical visual processing pathway that allowed the normally suppressed auditory-related responses to give rise to that patient's visual experience of sounds. Although developmental synaesthesia might arise through different means, these cases do provide the hypothesis that synaesthesia from drugs or pathology employs normal neural connections that somehow become disinihibited and produce experiences that normally would be suppressed (Grossenbacher & Lovelace, 2001).

Visual qualia in the blind

Experiences associated with the deprived modality, both in the form of concurrent sensations and hallucinations, are amply documented both in patients with peripheral and central pathology. Concurrent synaesthetic sensations tend to be simple in appearance, and often take the form of color patches, although quite complex three-dimensional shapes have also been reported. Hallucinations that occur frequently both in patients with peripheral and central blindness range from simple photisms to complex objects (Kölmel, 1985), and even include people moving through the lost visual field (Gloning, Gloning, & Hoff, 1967). Their appearance seems linked to specific cortical regions whose direct electrical stimulation during neurosurgery also generates phenomena of different complexity and kind (Wieser, 2003). Evidence from functional neuroimaging supports this inference both for hallucinations (ffytche et al., 1998) and for synaesthetic concurrents (Nunn et al., 2002; Paulesu et al., 1995). Moreover, Transcranial Magnetic Stimulation (TMS involves the use of a non-invasive, strong magnetic field to modulate cortical activity) applied over the visual cortices can induce visual phosphenes (Cowey & Walsh, 2000), and so do prostheses implanted in the visual cortex (Dobelle, 2002), the optic nerve (Duret et al., 2006) or the retina (Gekeler, Messia, Ottinger, Bartz-Schmidt, & Zrenner, 2006). Together, these data indicate that electromagnetic stimulation (phosphenes), endogenous activation (hallucinations), and activation induced by stimulation of an alternative intact sensory pathway (concurrents) can induce conscious visual sensations in the blind who have lost sight due to loss of retinal input or to lesions of the primary visual cortex. The patients' lesioned visual system must thus retain the potential to generate visual qualia.

Normal synaesthesia

All of us possess extensive connections between the different sensory modalities. They are found in cortical as well as sub-cortical structures of our brain, and induce the facilitating effects that stimulation with corresponding images and sounds – image of a dog and sound of a bark, image of a bird and sound of its song – exert both at the level of the neuronal and the behavioural responses (Stein and Meredith, 1990). Some researchers have examined the possibility of 'natural' cross-modal mapping extending past the object level, such as a dog barking, to simple features, such as hearing a musical note and seeing a flash of light. Our language often suggests such equivalences, as when a frequency is described as either high or low pitch. To learn whether the terms "high" and "low" influence one's perception of space, Walker and Smith (1984) used a variant of the Stroop test to examine how incidental tones that were either high or low pitch affected a lexical decision task. Subjects were to respond only to words shown on a computer screen. If the words "up" or "top" appeared, they were to press one key; if the words "down" or "bottom" appeared they were to press another. The tones played simultaneous with the appearance of the words, however, were to be ignored. Walker and Smith found that subjects were quicker to respond when the auditory tone and the word were congruent (that is, a high pitch occurred at the same time as the word "up"), and slower to respond when the tone and words were incongruent (that is, a low pitch occurred at the same time as the word "up"). This supports the idea that the labeling of an auditory pitch as high or low is not just metaphorical, but actually has an automatic impact on one's perception of the world. Importantly, the subjects were not synaesthetes, and this effect seems to derive from some crosswiring between auditory pitch and spatial representation that exists normally. Mudd (1963) performed a qualitative study to examine the natural correspondences that exist between a variety of auditory properties and visual space. Besides also noting the relation between auditory pitch and vertical location, he also reported the same relationship for auditory intensity; that is higher pitches and louder sounds were associated with higher vertical locations, but lower pitches and quieter sounds were associated with lower vertical locations. A recent report on 'implicit synaesthesia', a term coined to describe people who rank high on the 'Test of Genuineness' but do not report concurrent sensations (Steven, Hansen, & Blakemore, 2004), may suggest that normal, implicit, associator, and projector synaesthesia are spaced out over a continuum at whose end the concurrent sensation is explicitly phenomenal. If we all share the propensity for natural crossmodal synaesthesia, its basic mapping dimensions could possibly be exploited in the context of sensory substitution.

Sensory substitution for the blind

Sensory substitution for the blind converts visual information so that it can be processed by an intact sensory pathway. One of the first devices converted the signals from a video camera into tactile stimulation applied to the back of the subject who was seated in a chair designed for this purpose (Bach-y-Rita, Collins, Saunders, White & Scadden, 1969). Recent advances have allowed much smaller devices to provide the tactile information, most notably via stimulation of the tongue or forehead (for a review, see Bach-y-Rita & Kercel, 2003). The auditory modality rather than the somatosensory one was first targeted by Meijer (1992). His system, dubbed The vOICe, is mobile, and in addition to a video camera providing the visual input requires a small computer running the conversion program, and stereo headphones to provide the resultant sound patterns to the user. Meijer's program uses three major principles: horizontal location is coded by stereo panning and the time provided by the left-to-right scanning transformation of each image; vertical location is coded by frequency, so that up is represented by high frequencies and down by low frequencies; pixel brightness is coded by loudness, such that a bright white pixel is heard at maximal volume, and a dark pixel is silent. A more recently developed device, called the Prosthesis Substituting Vision with Audition (PSVA; Capelle, Trullemans, Arno, & Veraart, 1998), uses somewhat similar transformations for vertical location as well as brightness, but magnifies the center of the rather small image to simulate the visual system's emphasis on the macular region of the retina, and uses different tones to provide horizontal location directly, rather than through the left-to-right scan that The vOICe employs. The third substitution device is similar to The vOICe in terms of how vertical and horizontal locations are coded, but differs in the style of presentation and in how much pre-processing of the image takes place. SmartSight (Cronly-Dillon, Persaud, & Gregory, 1999; Cronly-Dillon, Persaud, & Blore, 2000) also codes vertical location by pitch; however, it presents the information in terms of musical notes, with the center of the image corresponding to middle C. Horizontal information is coded by time from left-to-right. The musical quality of the sound patterns is the most obvious difference when compared with The vOICe. Whereas The vOICe and PSVA depend on the ability of the user to learn to associate the complex sound patterns with objects and features in the visual world, SmartSight divides the image into different features. For example, a user could first listen to only the vertically-oriented edges, and subsequently listen to the horizontally-oriented edges, to then put the vertical and horizontal edge locations together to understand what the pieces combine to create.

All of these devices, somatosensory as well as auditory, have been tested on blindfolded and/or blind subjects, and the studies to date show that subjects can learn to interpret the information, and distinguish patterns of dots (Arno, Capelle, Wante-Defalque, Catalan-Ahumada, & Veraart, 1999) , orientations of Ts (Kupers et al., 2006), geometric shapes (Stoerig et al., 2004), and acquire knowledge of the spatial location of objects (Auvray, Hanneton, & O'Regan, 2003; Proulx, Stoerig, Ludowig & Knoll, 2006); even real objects (Auvray, Hanneton, Lenay, & O'Regan, 2005) or images of objects and scenes (Cronly-Dillon et al., 1999, 2000; Stoerig et al., 2004) seem to become classifiable or identifiable with training or extended use of the device (Poirier, Richard, Tranduy, & Veraart, 2006; see also Bach-y-Rita and Kercel, 2003).

Recordings of the brain activity associated with learning to use the devices has shown that visual cortices seem to become recruited into the analysis of the novel inputs especially in the blind (Arno et al., 2001;Kupers et al., 2006; Ptito, Moesgaard, Gjedde, & Kupers, 2005). They thus agree with previous studies that demonstrate that blind subjects activate even early visual cortex when involved in tasks ranging from reading Braille (Sadato et al., 1996), or sound localization (Weeks et al., 2000), to solving verbal memory tasks (Amedi et al., 2003). Disruption of visual cortical activity, whether by means of Transcranial Magnetic Stimulation applied over the occipital lobe (Cohen et al., 1997; Cohen et al., 1999; for a review see Floel & Cohen, 2006) or by a brain lesion (Hamilton, Keenan, Catala, & Pascual-Leone, 2000) interferes with the processing of these non-visual tasks, indicating that these cortices, when deprived of their normal retinal input, do in fact play a functional role in non-visual problem solving. It is important to note that synaesthetic or veridical visual sensations have generally not been reported in these studies, and this unfortunately indicates that visual cortical activation as such cannot be used to attest the presence of visual qualia. However, the fact that visual (V1, V2, V4, V8) and parietal cortical activation was also found in a late-blind synaesthete when he listened to time-words that induced spatially localized colors (Steven, Hansen & Blakemore, 2006) demonstrates that even the brain of a late-blind individual – he had been blind for 10 years – can still employ these areas to generate visual qualia in response to certain words. Conceivably, the visual cortex of the early-blind helps them to excel in a variety of non-visual tasks; in fact, several studies have demonstrated that the visual cortices of the early-blind appear to be more involved in these tasks than in the late-blind (Cohen et al., 1999). However, by virtue of not having been appropriately stimulated by retinal input, the visual cortex of the early-blind may not develop or maintain its propensity to provide phenomenal visual representations. In contrast, people who lose sight later in life may respond to visual deprivation with synaesthetic or hallucinatory vision.

Goals of visual substitution

By providing information about silent objects that are out of reach, sensory substitution ought to be useful for early and late-blind subjects (who can still hear or feel). As the early-blind have no or relatively short periods of vision, they usually face less problems in daily life than the late-blind. Moreover, the late-blind miss the easy access to information about objects and people outside of extra-personal space that sight provides. Visual substitution devices deliver this information, even though they are still a long way from allowing the ease of vision. A lot of perceptual learning is required for people to learn to understand the meaning of the new sensations, and the early-blind may have an easier time of it if they start using the systems early in life.

Early-blind subjects would probably experience sensations associated with the modality through which the substitution device delivers the information even when they recruit their visual cortex for the processing. A recent study by Kupers and colleagues (2006) supports this prediction. The authors trained early- and late-blind as well as sighted subjects to use a substitution system that converts visual input into electrotactile patterns on the subject's tongue (see Bach-y-Rita & Kercel, 2003). Following successful training, the authors used Transcranial Magnetic Stimulation to examine what sort of qualia would be associated with visual cortex stimulation. When the sighted subjects, who had been trained with the sensory substitution device, received TMS, they experienced visual phosphenes (they saw flashes of light as a result of the activation of their visual cortex), confirming that the visual cortex had not substantially deviated from its established visual role. In contrast, three of the eight early-blind subjects reported sensations on the tongue, but none reported visual phenomena. How about the five late-blind subjects? A tingling on the tongue occurred in only one, but two reported visual sensations, indicating that sensory substitution may in fact be able to induce 'synthetic' synaesthesia with concurrent sensations derived from the deprived modality.

Normal (developmental and deprivation-induced) synaesthesia does not seem to reflect features of the external world. However, they can be used to identify something that is rendered invisible by presenting it in the visual periphery under conditions of 'crowding'. Ramachandran & Hubbard (2001b) asked their volunteers to fixate on a central spot, and presented a single digit off to one side. All subjects found it easy to identify the digit. However, when it was surrounded by four other numbers ('crowding'), one on each side, identification of the target fell to chance – in non-synaesthetes. The two color-grapheme synaesthetes they tested, however, still reported seeing the color induced by the target number, and correctly inferred its identity on the basis of this color. Their remarks, such as "I can't see that middle letter but it must be an 'O' because it looks blue" (p. 8, Ramachrandran & Hubbard, 2001b), and their performance demonstrate that synaesthetic sensations may in fact be useful. Note that Hubbard, Arman, Ramachandran, & Boynton, 2005, report that not all synaesthetes show this performance benefit in crowding tasks, again attesting to the inter-individual variability of the phenomena.

'Synthetic' synaesthesia

As described above, late-blind people may experience visual sensations in the form of phosphenes or fully-formed hallucinations. That sensory substitution devices can induce visual concurrents has been shown by Kupers et al. (2006) in two of their five late-blind participants. In addition to the pleasure visual sensations can give to the blind (Cowey & Walsh, 2000), and the enrichment of the perceptual world they cause, these concurrents may be useful *if* they can provide information about the external world. To serve this purpose, the concurrents would not need to correspond to what a sighted person may see. As shown by the 'crowding' experiment cited above, a concurrent may substitute for otherwise unavailable information provided it is firmly associated with a particular stimulus. Say if a round object always elicited an experience of green, while angular objects do not, then seeing green would carry veridical shape information.

Could it also be possible to induce concurrent sensations that correspond to the world yet more directly? Although visual substitution may well be successful without inducing synthetic synaesthesia, let alone a veridical one, we and others, like Peter Meijer, who developed The vOICe, are pursuing this work in the hope that it will prove to be possible. As yet, the negative evidence is strong. Research has shown activity in primary visual cortex in the brains of blind or blindfolded patients doing a tactile task has not been accompanied by concurrent visual qualia that is evoked by the tactile sensations (Sadato et al., 1996; Pascual-Leone & Hamilton, 2001). Studies of sensory substitution that demonstrated successful perceptual learning as well as visual cortical activation in blind subjects have not reported any visual sensations on the part of their subjects (Arno et al., 1999; Cronly-Dillon et al., 1999, 2000; Poirier et al., 2006; Ptito et al., 2005), and our recent work with sensory substitution has found that the ability to interpret the sounds created by image-to-sound conversion can be accounted for by the activity in auditory cortex alone (Pollok, Schnitzler, Stoerig, Mierdorf, & Schnitzler, 2005). However, there is also some positive evidence. Kupers et al. (2006) described tingling tongues, but, in the late-blind, some visual sensations from visual cortical stimulation as well, although their subjects had received only basic training in sensory substitution over a short period of time. This is remarkable because the two or three weeks commonly used for formal training and testing are too short to allow even the automatic reading-out of the system's information that Bach-y-Rita, pioneer of this line of research, invokes. Clearly, such automaticity is necessary to free the sensory modality used to provide visual input for its primary – hearing or feeling – tasks, and a lot of perceptual learning must go into establishing it. That time also plays an important part for visual substitution to induce visual concurrents is suggested by a late-blind user of The vOICe system. She has used it on a regular basis for several years, and described instances when she not only experienced visual phenomena, but actually saw what she was hearing (Fletcher, 2002). We have conducted research with a sighted subject who was blindfolded for 21 days during which he used the vOICe system. He too reported a few instances where saw ‘like a hallucination’ what he was hearing through the device, and correctly described it. In his case, the propensity of the deprived system to provoke visual hallucinations may have contributed to lending the information its visual gestalt (see also Merabet et al. 2004).

Whether these are isolated instances, or something that can be permanently ingrained with training requires much more research. Extended use of the device may be one necessary condition, and a visual system still prone to generate visual qualia, another. Third, substitution systems that take advantage of natural correspondences between vision and audition or touch (e.g., Walker & Smith, 1984) and allow the other sensory systems to exploit their natural connections with the visual system, may not only facilitate the extensive perceptual learning, but the induction of synthetic synaesthesia that provides qualia for the missing sensory modality as well. Sensory substitution challenges the brain’s plasticity. Should it, given time and training, be able to learn to generate visual concurrents that correspond to the auditory or tactile information the substitution system provides, the future will not only hold tingling ears and tongues for the blind, but look distinctly bright.

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