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The State of the Art of Sensory Substitution

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As an introduction to the special issue of Multisensory Research on Sensory Substitution (SS) we would like to give an overview of the limits and promises of this growing field of research. It seems that a large part of the scientific community considers that sensory substitution does not work. Yet many research groups claim that it does, and are making advances and obtaining interesting results, many of which are described in this special issue, that support their case. Why is there this discrepancy? It is likely that the term 'sensory substitution' induces a narrowing of the field of research, linked to the original idea of fully restoring a lost sensory modality by artificially providing the information through another sense (e.g., Bach-y-Rita et al., 1969; see also Bach-y-Rita, 1972). However, such an ambitious claim has long been abandoned, and many researchers agree that SS is never going to be the way to achieve full recovery of the use of a lost sense. Many researchers do however agree that a restricted form of sensory substitution can be achieved. Thus, it is undeniably the case that many abilities of people with sensory loss can be significantly enhanced by the use of SS devices. To some extent, therefore, sensory substitution does work.

Reflecting the fact that SS researchers have had to retract from their original ambitious aim, several alternative names for this cross-modal approach have been proposed such as 'perceptual supplementation' (Lenay et al., 2003) and 'sensorimotor extension' (Auvray and Myin, 2008). However, none has so far received universal acceptance. This may reflect the fact that, although SS

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had its origins in the 60s with the pioneering work of Paul Bach-y-Rita et al. (1969), the field is still young. Many theoretical questions remain to be solved before a name emerges that truly represents the use and limitations of technologies that seek to provide input normally provided by one sense by means of another.

Using the word 'sensory' denigrates the importance of action in learning to use SS devices (Auvray and Myin, 2008; Lenay et al., 2003). The use of the term 'perceptual' has also been challenged, for instance by Deroy and Auvray (2012, 2014), who suggested that the perceptual paradigm framing studies of SS has constrained its investigation and biased the interpretation of the results regarding training, subjective, and neurological changes. Under this view, it is time to go beyond the 'dominance versus deference' debate that focuses on whether the obtained experience is akin to the sense being replaced or to the sense through which the information is transmitted. All visual information transduced by, for example, the auditory system could continue to be perceived as sound, even though it now carries information not normally conveyed by sound. Alternatively, it can be interpreted as visual. Or is it possible we could create a totally novel sense; one not experienced at all by people with healthy sensory systems? Rather than requiring this debate to be solved, we may adopt a compromise and treat SS as a 'half perceptual, half cognitive' process that takes integration of the novel information with the existing perceptual-semantic route into account. More research on the processes involved in SS needs to be conducted to better understand if the experiential outcome of pumping one type of information through sensory channels that have evolved to process quite different information is best regarded as sensory, perceptual, cognitive, or some combination.

To choose between the terms substitution, rehabilitation, supplementation, and augmentation, more research needs to be conducted investigating the quantitative and qualitative aspects of the experience associated with using these devices. How similar is it to the experience normally provided by the lost sense? An ideal SS device would allow normal abilities, comparable to those produced by the simulated sense. A lower resolution is probably inevitable reflecting the different information-carrying capabilities of the exploited channel and the fact that we generally expect this channel to continue to function normally despite extra information being piggy-backed onto it. Research on the abilities and their perceptual and cognitive correlates may allow us to take a better stance on this.

In the meantime, what can be agreed on is that, at least in their current stage of development, no SS device exists that allows the full spectrum of experience provided by a lost sense. The initial over-optimistic aims to completely restore a sense through exploiting another route into the brain have now been cut down into more realistic research questions: (1) How to define SS and its limitations?

(2) How much rehabilitation can we expect from existing SS devices? and (3) What are the experimental and theoretical perspectives that SS opens on cognition in general?

(1) The question of how to define SS and its limitations — which goes hand in hand with the question of terminology — crucially determines what we expect and how we understand and communicate about the experiential consequences of SS. If we choose a too all-encompassing definition, this will risk losing the research topic by drowning it (for instance into a field as broad as multisensory technology). On the other hand, if we choose a too narrow definition, focusing on the idea of an exact substitution of one sensory modality by another, then, as is nicely formulated by Elli, Benetti and Collignon (this issue), there might never be a future for SS outside academic laboratories. An additional reason to not want to hold out for the total replacement of a lost sense is that this approach ignores the specificities and limits of each sensory modality. To take the example of conversion of visual into tactile information, as is described by Spence (this issue), there are perceptual, attentional, and cognitive limitations that forcibly constrain the amount and type of information that can be provided through the tactile modality.

(2) Another reason for not pursuing the unreachable aim of seamlessly restoring the full range of functionalities of a lost sense by SS is that such a mythical holy grail detracts from the scientific investigation of the many technologies that presently exist, and which are successfully used by sensory-impaired persons in specific activities such as navigation or pattern recognition. In this special issue, examples of such devices enlighten the variety of sensory modalities that can be used as the substituting or substituted modality. Klatzky, Giudice, Bennett and Loomis (this issue) review the promises of touch-screen technology to provide spatial information to blind persons. In the field of visual-to-auditory conversion, Maidenbaum, Levy-Tzedek, Chebat, Namer-Furstenberg and Amedi (this issue) present studies on navigation performed with a minimalist device, the virtual-EyeCane. Brown, Simpson, and Proulx (this issue) investigate the resolution that we need when using the auditory–visual substitution device known as Voice (Meijer, 1992). The promises of SS devices for rehabilitating deficits in postural control are instantiated by Diot, Halavackova, Demongeot and Vuillerme (this issue) who have made important advances with a vestibular-to-tactile device.

(3) Finally, SS provides a channel for investigating broader scientific questions such as cortical plasticity and phenomenology. Gagnon, Kupers and Ptito (this issue) tackle the under-investigated field of the chemical senses highlighting the consequences of congenital blindness and congenital anosmia on olfaction and taste. SS can also enlighten the processes involved in spatial

cognition and the interesting phenomenon of distal attribution as described by Hartcher-O'Brien and Auvray (this issue).

We leave you to discover in depth all these aspects of sensory substitution, hoping that this will provoke the same enthusiasm in you as we had when reading them.

The Special Issue Papers

1. Elli, G. V., Benetti, S. and Collignon, O. Is there a future for sensory substitution outside academic laboratories?
2. Spence, C. The skin as a medium for sensory substitution.
3. Diot, B., Halavackova, P., Demongeot, J. and Vuillerme, N. Sensory substitution for balance control using a vestibular-to-tactile device.
4. Brown, D. J., Simpson, A. J. R. and Proulx, M. Visual objects in the auditory system via sensory substitution: How much information do we need?
5. Klatzky, R. L., Giudice, N. A., Bennett, C. R. and Loomis, J. Touch-screen technology for the dynamic display of 2D spatial information without vision: Promise and progress.
6. Maidenbaum, S., Levy-Tzedek, S., Chebat, D. R., Namer-Furstenberg, R. and Amedi, A. The effect of extended sensory range via the EyeCane sensory substitution device on the characteristics of visionless virtual navigation.
7. Gagnon, L., Kupers, R. and Ptito, M. Making sense of the chemical senses.
8. Hartcher-O'Brien, J. and Auvray, M. The process of distal attribution illuminated through studies of sensory substitution.

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