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Editorial

Multisensory integration, sensory substitution and visual rehabilitation

ABSTRACT

Sensory substitution has advanced remarkably over the past 35 years since first introduced to the scientific literature by Paul Bach-y-Rita. In this issue dedicated to his memory, we describe a collection of reviews that assess the current state of neuroscience research on sensory substitution, visual rehabilitation, and multisensory processes.

Dedicated to the memory of Paul Bach-y-Rita (1934–2006).

Paul Bach-y-Rita, Ph.D. (1934-2006)

Dear Readers,

Thirty-five years ago, Paul Bach-y-Rita and colleagues published a short paper that introduced a radical idea: people deprived of one sense, such as sight, could regain access to that missing information if it were transformed into a format that another intact sense could process (Bach-y-Rita et al., 1969). As Paul often emphasized in the ensuing years, we see with our brain, not with our eyes; thus, if the missing input is provided via another sense, the brain can sort out which aspects of the information are of a visual nature. They demonstrated the viability of this idea by translating an image into a tactile projection felt on the back in a repurposed dental chair. The white pixels of the image were impressed on the skin and the black were not, such that a tactile impression of the image would be felt. With some training, one could see by feeling and interpreting the pattern pressing on the back, and even react in real time to a live camera feed.

The field as advanced remarkably, and in many directions, from the germ of Paul's idea. The idea for this special issue of *Neuroscience and Biobehavioral Reviews* arose during a symposium at the International Multisensory Research Forum on "Multi-sensory integration, sensory substitution technology and visual rehabilitation" (Fukuoka, Japan, 2011). This opening symposium for the meeting provided an update on the ways that sensory substitution has developed from an idea for vision restoration to an integrated part of multi-sensory research in the domains of cognitive science and neuroscience. Paul reviewed the relevance of sensory substitution research for cognitive science just over a decade ago (Bach-y-Rita and Kercel, 2003). Even in this short time, the developments to the field have been astonishing. This collection of reviews brings together not only work on the neuroscience of sensory substitution, but presents it in the context of other related issues in research examining the multisensory nature of perception more broadly.

Paul passed away a few years ago, and we dedicate the work in this volume to his memory. We think he would be pleased, and perhaps even surprised, by the advancements in neuroscience and behavioral research on this topic, and its integration with other areas of research. The special issue begins with three articles that deal explicitly with sensory substitution. First, Maidenbaum et al. (2014) discuss how knowledge in sensory substitution research has advanced sufficiently to take the technology out of the lab and into the world as practical devices for visual rehabilitation. A key aspect for the viability of sensory substitution relies on training the brain to interpret the novel input correctly, and Maidenbaum et al. describe potential training protocols. Proulx et al. (2014) introduce a novel model for multisensory perceptual learning that builds on the reverse hierarchy theory. Clearly the training regimens developed for sensory substitution devices for the blind would be most beneficial if learning can be generalized and not just specific to the trained tasks or stimuli. Proulx et al. provide a neural and psychological framework that can guide the development of such training programs, and connect that applied research to the basic research of perceptual learning. The third paper focusing on sensory substitution is by Ward and Wright (2014), who suggest that sensory substitution displays similar properties to synesthesia, a condition where stimulation of one modality evokes a perceptual experience in another modality. Their review suggests that the visual

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experiences evoked by sensory substitution might arise from similar mechanisms as other multisensory processes.

The special issue then includes three articles that present different viewpoints on what blindness reveals about functional brain organization and neuroplasticity. The prior reviews by Maidenbaum et al. and Proulx et al. both suggest that the brain has a "metamodal" organization that is organized by computation, or task, rather than by sensory modality. The following papers look into the detailed evidence from the neuroscience of the blindness to provide novel insights for the functional neuroanatomy of the blind and sighted brain. First, Kupers and Ptito (2014) assess the role of visual experience for brain organization, the development of consciousness, and how the congenitally blind form an image of the world. Renier et al. (2014) then present a review of the potential mechanisms for the cross-modal plasticity that takes place in the sensory deprived brain. Specifically they assess how the neural Darwinism theory explains the results from neuroscience research carried out with humans and non-humans animals. The final review on the insights from blindness for brain organization is by Ricciardi et al. (2014), who conclude that the evidence supports a supramodal, or modality independent, organization of the brain.

The symposium that gave rise to this special issue aimed to connect research on sensory substitution and blindness to the wider field of multisensory processing. This goal is also present in this special issue with the inclusion of two papers that extend to broader areas of multisensory neuroscience. Rowland and Stein (2014) review the mechanisms of multisensory versus unisensory integration in terms of the temporal profile of multisensory integration at the level of single neurons and introduce a model of the linear and nonlinear aspects of multisensory integration consistent with the evidence. In the final article of the special issue, Apps and Tsakiris (2014) provide a perspective on multisensory neuroscience at the higher level of self-awareness via the free-energy account of cortical function.

The articles collected here offer novel insights and excellent snapshots of the current knowledge for a number of domains. We are certain this special issue will reveal the importance of multisensory, visual deprivation, and sensory substitution approaches to understanding the nature of brain organization and function.

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References

Apps, M.A.J., Tsakiris, M., 2014. The free-energy self: a predictive coding account of self-recognition. Neurosci. Biobehav. Rev. 41, 85–97.
Bach-y-Rita, P., Collins, C.C., Saunders, F.A., White, B., Scadden, L., 1969. Vision substitution by tactile image projection. Nature 221 (5184), 963–964.
Bach-y-Rita, P., Kercel, S.W., 2003. Sensory substitution and the human-machine interface. Trends Cogn. Sci. 7 (12), 541–546, pii:S1364661303002900.
Kupers, R., Ptito, M., 2014. Compensatory plasticity and cross-modal reorganization following early visual deprivation. Neurosci. Biobehav. Rev. 41, 36–52.
Maidenbaum, S., Abboud, S., Amedi, A., 2014. Sensory substitution: closing the gap between basic research and widespread practical visual rehabilitation. Neurosci. Biobehav. Rev. 41, 3–15.
Proulx, M.J., Brown, D.J., Pasqualotto, A., Meijer, P., 2014. Multisensory perceptual learning and sensory substitution. Neurosci. Biobehav. Rev. 41, 16–25.
Renier, L., De Volder, A.G., Rauschecker, J.P., 2014. Cortical plasticity and preserved function in early blindness. Neurosci. Biobehav. Rev. 41, 53–63.
Ricciardi, E., Bonino, D., Pellegrini, S., Pietrini, P., 2014. Mind the blind brain to understand the sighted one! Is there a supramodal cortical functional architecture? Neurosci. Biobehav. Rev. 41, 64–77.
Rowland, B.A., Stein, B.E., 2014. A model of the temporal dynamics of multisensory enhancement. Neurosci. Biobehav. Rev. 41, 78–84.
Ward, J., Wright, T., 2014. Sensory substitution as an artificially acquired synaesthesia. Neurosci. Biobehav. Rev. 41, 26–35.

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