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Review article

Improving training for sensory augmentation using the science of expertise

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ABSTRACT

Sensory substitution and augmentation devices (SSADs) allow users to perceive information about their environment that is usually beyond their sensory capabilities. Despite an extensive history, SSADs are arguably not used to their fullest, both as assistive technology for people with sensory impairment or as research tools in the psychology and neuroscience of sensory perception. Studies of the non-use of other assistive technologies suggest one factor is the balance of benefits gained against the costs incurred. We argue that improving the learning experience would improve this balance, suggest three ways in which it can be improved by leveraging existing cognitive science findings on expertise and skill development, and acknowledge limitations and relevant concerns. We encourage the systematic evaluation of learning programs, and suggest that a more effective learning process for SSADs could reduce the barrier to uptake and allow users to reach higher levels of overall capacity.

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1. Introduction

Sensory substitution and augmentation devices (SSADs) provide perception beyond a user's normal sensory capabilities by compensating for the loss of sensory function or by providing additional information not available to existing senses. They were initially described as merely translating one sensory property of the world into another – 'sensory substitution' (Bach-Y-Rita et al., 1969), but recently the view has been advanced that SSADs provide novel sensory experiences that should be thought of in terms of function and purpose, rather than compared with existing experience – 'sensory augmentation' (Auvray and Myin, 2009; McGann, 2010; Stafford et al., 2011).

SSADs have the potential to be hugely useful in research and in use by the wider public. As a research tool they provide insight into the cognitive and neural processes behind the development

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and experience of sensory perception and sensorimotor learning (Levy-Tzedek et al., 2012; Ortiz et al., 2011; Stiles and Shimojo, 2015; Maidenbaum et al., 2016; Ward and Meijer, 2010). They also have potential as assistive technology – aiding people with sensory impairment as a result of injury or disability, or providing assistance to people working in poor environmental conditions (Auvray et al., 2007; Bertram et al., 2013; Maidenbaum et al., 2014). Thanks to the growth in the computing power and reduction in size and cost of smartphones and other technology, there has been a dramatic increase in what is possible from a practical and portable, a trend exemplified by the vOICe device (Auvray et al., 2007; Ward and Meijer, 2010). However, despite the potential benefits of SSADs, their full potential remains unrealised: SSADs are not as widely used as more familiar, yet more rudimentary assistive technology, such as the white cane (Loomis, 2010), and while their use as a research tool is flourishing, there are many further opportunities.

Over 40 years have passed since the first SSAD offered the possibility of restoring vision, there has been little penetration of SSADs into the assistive technology market. Over ten years ago, Lenay and colleagues noted that Bach-y-Rita's prediction that SSADs would revolutionise assistive technology remained unfulfilled (Lenay et al., 1991). That prediction is arguably still unfulfilled. This raises the question: How can we work to help SSADs fulfil their potential?

Underuse is not a problem that is unique to SSADs. SSADs can be considered a subset of the wider category of assistive technology. Although there is an increase in the adoption of assistive technology, a substantial proportion of devices go unused or are later abandoned (Phillips and Zhao, 1993). Assistive technology programs can involve large upfront costs of time, effort, and money, on the part of both the patient and the technology provider (Andrich and Carricciolo, 2007). If these benefits are not realised, then the investments of provider and user are wasted. It is therefore in the interests of both the provider and the recipient to ensure that devices are suitable for their task and properly supported.

The factors underlying rejection and abandonment of traditional assistive technology have been a focus of previous study, and these factors may inform why SSADs are not more widely used. Understanding why a piece of assistive technology is used or not involves assessment of the technology, its capabilities, and how well it performs, but also assessing the needs the user and their attitudes towards the technology (Phillips and Zhao, 1993). Surveys of assistive technology users have revealed that many of the factors relate to balancing the benefits gained by using a device against the cost of time, money and effort invested in learning to use it (Phillips and Zhao, 1993; Batavia and Hammer, 1990). Improving the efficiency of learning to use an SSAD is one way to improve this balance and make their use as an assistive technology and a research tool more appealing. We suggest that the contribution of SSADs to cognitive science as a research tool can be reciprocated by applying existing knowledge from cognitive science to improve the process of learning to use SSADs.

Provision of support and training was identified as a factor in the abandonment of traditional assistive technology (Phillips and Zhao, 1993; Batavia and Hammer, 1990) and it has been suggested as a factor in improving SSAD use (Elli et al., 2014; Maidenbaum et al., 2014). In the present paper, following a summary of the applications of SSADs and the reasons why they may be rejected, we suggest how the findings of cognitive science can be leveraged to improve the process of learning to use an SSAD. We begin with how the science of expertise can be used to analyse the behaviour of existing practitioners and used to guide training. We then discuss how training programs might be improved. We first address instructed training, including a review of the current approach to training in the SSAD literature, then go on to highlight other approaches to improving training as well as routes to developing proficiency that do not focus on direct instruction, and finally draw attention to some of the limitations and drawbacks of training. We conclude by touching on how the improving the design of SSADs can be used as an alternative method to improve learning.

2. SSADs as research tools and assistive technology

Paul Bach-y-Rita developed the Tactile Visual Substitution System, often regarded as one of the earliest sensory substitution and augmentation device (SSAD) "as a practical aid for the blind and as a means of studying the processing of afferent information in the central nervous system" (Bach-Y-Rita et al., 1969), and SSADs today still represent an opportunity to assist individuals with sensory impairment and to study sensory processing. SSADs typically take parameters from one sensory modality, recode it, and present it in another modality. In the case of the vOICe (Auvray et al., 2007), one of the most commonly used SSADs, an image taken from a camera is encoded as sound. Each pixel is encoded as a sinusoidal tone, where the vertical location of the pixel determines the pitch of the tone, its luminance determines the volume. To represent the horizontal location, the vOICe sweeps across the image from left to right, playing each vertical row of pixels in sequence and panning from left audio channel to the right.

Because SSADs often substitute input in one sensory modality for another, they are commonly referred to as sensory substitution devices (SSDs). However, it has been suggested that the experience provided should be considered as neither that of the substituted sense nor the substituting sense, but instead as a distinct sensory experience that is better understood as a way of interacting with the world (Auvray and Myin, 2009; McGann, 2010; Stiles and Shimojo, 2015) Further, some devices do not substitute, but instead provide information that is not naturally available to the existing senses, such as indicating the direction of north (Nagel et al., 2005; Kärcher et al., 2012).Therefore the term 'sensory substitution device' can be extended to 'sensory substitution and augmentation device' (Auvray and Myin, 2009; Stafford et al., 2011; Bertram et al., 2013).

Users are not only able to use SSADs to interact with the world, but have also reported phenomenological sensory experiences. This has been reported by users with extensive experience of the device (Ward and Meijer, 2010), but also by users who had undergone just three months of training (Ortiz et al., 2011). Whether there are particular experiences with an SSAD that could lead to the development of conscious experience and whether there are individual differences in the likelihood of developing them would be a rich research topic within sensory perception. Input from SSADs can drive subcortically supported behaviour such as visual saccades in the absence of conscious understanding (Wright et al., 2012), but is susceptible to top-down conscious influence (Murphy et al., 2016). As experience with a device progresses, processing the stimuli involves areas of cortex involved in higher level feature processing and identification (Striem-Amit et al., 2012a; Striem-Amit and Amedi, 2014). SSADs have been suggested as a controlled method of studying cross-modal plasticity following sensory impairment and a potential biomarker for adaptability to more invasive vision restoration technologies (Nau et al., 2015a).

As assistive technology, modern SSADs are applied to activities of daily life such as reading, object recognition, and navigation of the environment (Striem-Amit et al., 2012a; Maidenbaum et al., 2016; Nau et al., 2015b). A substantial number of SSADs focus on providing visual information, and SSADs have been presented as an alternative to retinal implants as a method for restoring visual function (Striem-Amit et al., 2012b). Retinal implants involve inserting an electrode array that stimulates the retina according to the luminance of a detected scene, in a similar way to SSADs translating a scene; the stimulation produces phosphenes, and the experience can be used to navigate (for a review of the progress of retinal