The blind get a taste of vision

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Introduction

Sensory substitution and cross-modal plasticity

In sensory substitution, a given sensory modality acquires the functional properties of a missing one. This phenomenon is due to a reorganization of the sensory systems that are deprived of their normal input through a process called cross-modal plasticity [1]. ‘Rewiring’ studies carried out on ferrets [2] and hamsters [3] provided strong support for these phenomena. For example, lesions of central retinal targets induce the formation of new and permanent retinofugal projections into non-visual thalamic sites such as the auditory nucleus [3]. Single neurons in the auditory cortex of these rewired animals respond to visual stimuli and some of them respond equally well to auditory as to visual stimuli. Moreover, those cells that respond to visual stimuli show properties (e.g., orientation selectivity, motion and direction sensitivity) similar to those encountered in the visual cortex of normal hamsters. At the behavioral level, rewired hamsters can learn visual discrimination tasks as well as normal animals and a lesion of their auditory cortex provokes cortical blindness [4]. These data raise the question whether similar processes happen in congenitally blind humans. The absence of visual input from birth leads to the recruitment of the visual cortex by other sensory modalities such as touch or audition [5]. Most studies in man have been carried out in blind subjects who have had many years of experience with Braille reading and it is difficult to conclude on brain reorganization since the extensive reliance of these subjects on tactile or auditory stimulation may by itself result in enhanced activity in the occipital cortex [6, 7]. To avoid this bias, we took advantage of the tongue display unit, a tactile to vision sensory substitution device which does not use the fingertips or the auditory system and which is therefore equally novel for early blind, late blind and healthy controls. This device translates visual information into electrotactile stimulation which is delivered to the tongue by means of an electrode array.

The tongue display unit (TDU)

The tactile visual substitution system (TVSS) comprises the TDU, a laptop computer with custom made software and an electrode array (3×3 cm) consisting of 144 gold-plated contacts each with a 1.55 mm diameter arranged in a 12×12 matrix. The device has an update rate of 14–20 frames per second. An electrical pulse (40 μs positive pulse) is generated when a stimulus is presented. The TDU is the descendant of a series of devices developed by the late Pr. Paul Bach-y-Rita over half a century of research. Bach-y-Rita experimented with the potential of the skin as a channel for transmitting pictorial material [8]. The basic idea was to transmit real time images from a video camera to the skin *via* electro- or vibrotactile stimulation. The first systems translated the video images from the camera into vibrotactile stimuli which were delivered to the back of the subjects *via* a 20×20 matrix of solenoid vibrators, spaced 12 mm apart, mounted on the back of a dentist’s chair. The 400 stimulators covered 645 cm^2 of the back and enabled subjects to recognize certain shapes and to make judgments about object orientation. These early prototypes were bulky and lacked mobility and maneuverability. Therefore, Collins and Bach-y-Rita conceived a more portable version in 1973 [9]. In this system, the lens of a light-weight camera was mounted on a pair of eyeglasses. The information captured by the camera was translated into electrotactile stimuli that were relayed in a point-to-point manner to the abdominal skin *via* a flexible electrode matrix. Case studies with such devices demonstrated that it was possible to make distance discriminations and even to catch objects in motion [10]. In the late 1990s, the device was adapted to stimulate the tongue instead of the abdomen. Thereto, the device was further miniaturized and made more aesthetically acceptable by hiding the electrode matrix inside a small dental retainer [11]. The new 49 points (7×7 array) matrix proved to be more efficient when stimulation was delivered to the tongue instead of the fingertips. Moreover, tongue stimulation only required a fraction (3%; 5–15 V) of the voltage needed for stimulation of the fingertips. A better image resolution was obtained by augmenting the number of electrodes in the matrix placed on the tongue from 49 to 144 points (see Fig. 1). Point-to-point tactile discrimination capacity of the tongue is superior to that of the skin of the back that allows more information to be presented to a smaller skin surface. The tongue representation in the primary somatosensory cortex also covers a much larger area than that of the back, making it a highly sensitive tactile organ.

The TDU was recently adapted for navigational purposes (Brainport, WICAB Inc., Wisconsin, USA). The portable system consists of a webcam connected to a laptop and a tongue stimulator array of 100 small electrodes with a diameter of 1 mm, spaced 1 mm apart and arranged in a 10×10 matrix. The entire tongue array measures 2×2 cm, and can be comfortably placed on the tongue due to its smooth and soft silicone mouthpiece, which rests on the roof of the mouth (see Figs 2, 5). This model has the advantage of being much smaller than previous versions, thereby enabling true mobility of the user for navigating and exploring his surroundings.

FIGURE 1. THE TONGUE DISPLAY UNIT (TDU) AND ITS COMPONENTS.
Left: The TDU box and the tongue grid. Right: A subject being tested with the device.

Other haptic devices

Over the past two decades, haptic devices invaded many aspects of our daily lives, creating more efficient user-machine interfaces. Vibrating cell phones, video games and tactile displays have become commonplace in society today. There are also many haptic devices aimed at improving the quality of life of the blind in terms of accessibility to various types of visual information. We will present here only some of these devices that have been placed into two categories: those aimed at computer navigation, and those aimed at real world navigation.

Computer navigation

The Optacon (Optical to Tactile Converter) was one of the first set of devices aimed at helping blind people to navigate in a virtual computer world. The Optacon is an electro-mechanical system allowing blind people to view printed material that has not been transcribed into Braille or other pictorial representations. The Optacon consists of an electronic box connected to a lens and a tactile array on which the blind subject places his/her index finger. By moving the lens over a computer screen with printed text, the