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Short communication

Brain plasticity: ‘visual’ acuity of blind persons via the tongue

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Abstract

The ‘visual’ acuity of blind persons perceiving information through a newly developed human–machine interface, with an array of electrical stimulators on the tongue, has been quantified using a standard Ophthalmological test (Snellen Tumbling E). Acuity without training averaged 20/860. This doubled with 9 h of training. The interface may lead to practical devices for persons with sensory loss such as blindness, and offers a means of exploring late brain plasticity. © 2001 Elsevier Science B.V. All rights reserved.

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A person who has suffered the total loss of a sensory system has, indirectly, suffered a brain lesion. The loss results in an important reduction of the sensory input (more than a million fibers in the case of blindness) to the brain. A number of laboratory studies of sensory substitution have demonstrated that the information from artificial sensory receptors can be delivered to the brain, and subjective experiences of the lost sensory system can be experienced with training [2,5]. Blind children and adults have been able to recognize faces, observe and describe the flame of a candle, read, and locate objects and movement in three-dimensional space and perform complex hand ‘eye’ coordination tasks such as inspection and assembly of electronic components on a factory assembly line [1,2,5,9]. With practice, they subjectively locate the targets in space, rather than on the tactile interface.

A newly developed human–machine interface [3,4] offers the realistic possibility of practical, cosmetically acceptable devices for persons with sensory loss. The vision substitution system comprises a small, videoconferencing camera (Pixera PXG, FOV 54 H by 40 V, F/3.5, 3.7 mm lens), a video capture card (Nogatech Conference Card), a Dell Inspiron 7500 laptop computer, a tongue display unit (TDU), an electrode array (3 H by 3 V cm), and custom image processing software (Fig. 1). The camera image (240 H by 180 V pixels) was sampled and reduced to the 12×12 resolution of the tongue display by averaging adjacent pixels, with an update rate of approximately 14–20 frames/s.

The 12×12 tongue-placed electrode array (144, 1.55-mm-diameter gold-plated electrodes on 2.32-mm centers arranged in a square matrix) comprised four 6×6 square quadrants which were identically and simultaneously pulsed by the TDU in a raster-scan format. Each electrode in a quadrant first receives one 40-μs positive voltage pulse; 138 μs separates pulse onsets for adjacently pulsed electrodes. Following activation of all 36 electrodes in each sector (5 ms), this entire sequence is repeated two more times, followed by a 5-ms silent period. The result for any given electrode is a burst of three pulses at a rate of 200/s, with the bursts repeating continuously at a rate of 50/s.

The experimental group consisted of six sighted blindfolded (24±3.4 years) and six congenitally and totally blind (28±4.2 years) subjects, all using the tongue display unit for the first time. Congenitally blind students or employed persons, with no known medical or cognitive problems, constituted the experimental group, and the sighted subjects were all university students.

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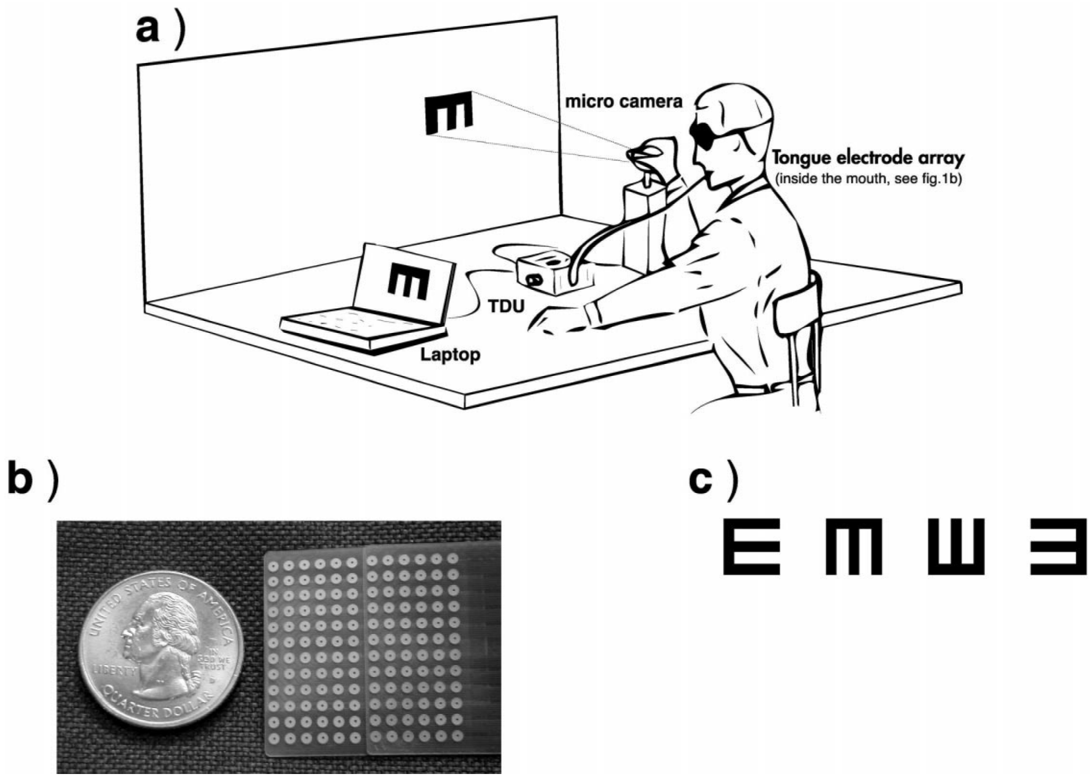

Fig. 1. Experimental apparatus. (a) A subject is shown using a tongue human–machine interface (TDU) connected to a TV camera and a computer. (b) The tongue electrotactile array (144 points, measuring approximately 3 cm square) is shown next to a US quarter for size comparison. (c) The Snellen tumbling E is shown in its four directional orientations.

The experimental sessions, which lasted for 80 min, consisted of the random presentation of the Snellen E in six sizes (5, 3.6, 2.5, 1.8, 1.25 and 0.85 cm) and four orientations (Fig. 1c). The subject manually swept the camera over the Snellen E for up to 120 s (the mean exploration time for the large size stimuli was 60 s). The camera was mounted on a pedestal at a fixed distance (40 cm) from the target. A pivot allowed the subjects to use horizontal and vertical scanning movements; they received the image in real time (Fig. 1a).

Acuity was judged by performance at or near 100% correct response (Fig. 2). For the larger Snellen E's, only part of the object would be displayed on the tongue at any given time, which may have caused the slightly reduced performance at the 20/1720 Snellen ratio (corresponding to the 5 cm optotype size, which extends well beyond the size of the electrode array).

Subject response was analyzed in a $2\times6\times4$ (Visual status$\times$Snellen optotype size$\times$Snellen optotype orientation) mixed analysis of variance (ANOVA) with repeated measures of size and orientation. Without training, both groups averaged 20/860, with the performance of blind persons being slightly (not statistically significant) better for the small sizes.

The analysis revealed a significant effect: Snellen optotype size ($F(5,50) = 23.14$; $P < 0.0000001$). The analysis of individual subject responses points to the possibility, in some subjects, of even better acuity levels, such as a blind subject's performance that attained, without training, 20/430 (100% correct responses) and reached 75% of correct responses at the 20/240 level of acuity. One blind (of median performance) and one sighted person were selected for 9 h of training. Training consisted of detecting simple lines of various sizes and orientations and two lines forming 45° or 90° in different orientations. At the end of the training, the subjects were tested again with the Snellen optotypes, doubling their acuity to 20/430. The results are presented in Fig. 2.

Changes in brain activity are associated with sensory loss and the adaptation to that loss; they have been considered to represent brain reorganization [2]. Latency variations in the late components of the tactile [7] and auditory [12] evoked potentials, and differences in the tactile and auditory induced activity in the visual cortex of persons who became blind at either an early or a late age [10,11], are among the manifestations of the effect of the sensory loss and the resulting brain reorganization. Studies of the brain activity of Braille users have been documented [8]. Sensory substitution studies with persons with sensory loss have provided information on brain plasticity [2,6],

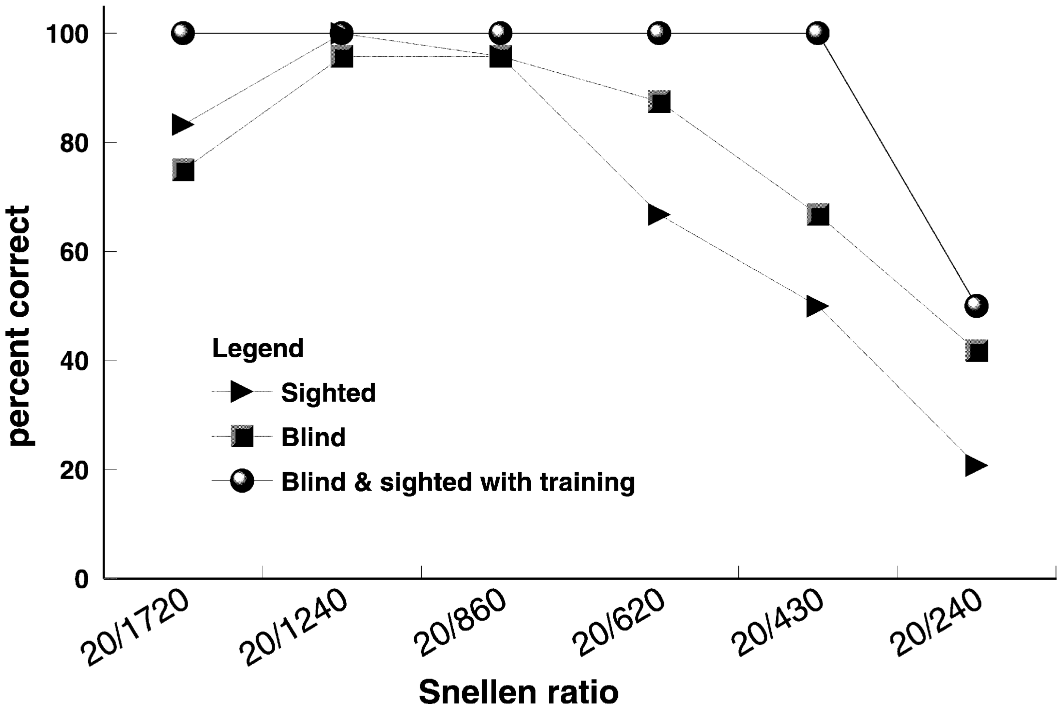

Fig. 2. Performances on the Snellen test (mean and standard deviation, computed for the percentage of correct responses for each Snellen ratio, are displayed in brackets): acuity responses of the sighted {(83.3; 11.8), (100; 0), (95.8; 9.3), (66.8; 23.5), (50; 14.5), (20.8; 9.3)} and blind {(75; 17.5), (95.8; 9.3), (95.8; 9.3), (87.5; 12.5), (66.8; 23.5), (41.8; 23.5)} untrained subjects are graphed. The correct responses of two of them, one blind and one sighted, are shown following 9 h of training.

but the results were obtained with experimental devices that had very limited use, strictly in a research environment, and thus may not have had effects comparable to those that would be produced with long-term functional use.

Our results demonstrate that 'visual' acuity with a sensory substitution system can be quantified, and that a human–machine interface through the tongue has the potential of leading to practical instrumental sensory substitution systems. The use of the peripheral and central structures of the intact somatosensory system to carry information from a substitute sensory receptor (e.g., TV camera in the case of blindness) will allow before-and-after studies to evaluate late brain plasticity related to sensory substitution.

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