Visual-to-auditory sensory substitution in proficient blind users:
Neural correlates and potential application in neuroprostheses research

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(Background image credits: IEEE Spectrum Magazine; Feb. 2004)

Summary

INTRODUCTION: Despite intensive effort, the restoration of truly functional vision in blind using neuroprostheses has not been achieved. We suggest that one major reason for this failure is that the brain of the blind undergoes profound plastic changes and we do not know enough about how to communicate with this altered cortex in order to generate meaningful visual perception. Towards this goal we propose that sensory substitution devices (SSD) can play a major role on two fronts:

1. 'Guide' visual cortex to 'read' and interpret visual information arriving from a retinal prosthesis.
2. To be useful in daily living activities such as object recognition and navigation.

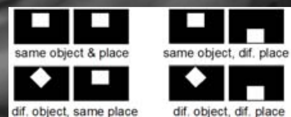
SUBJECT: A congenitally blind expert user of a visual-to-auditory SSD called "The vOICe".

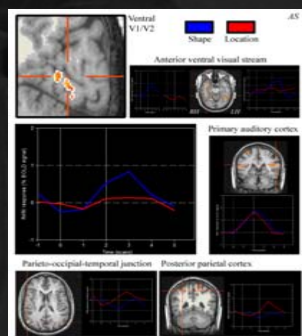
DESIGN: Two fMRI experiments were conducted, one which studied shape versus location processing of visual geometrical shapes transformed into "The vOICe" format and the second investigating natural objects defined by The vOICe, audition and touch.

RESULTS: Right hemisphere lateralized network of areas (including STS, LOC and PPX) participates in processing the vOICe information. Differential activation of ventral V1/V2 is associated with shape selectivity in both experiments.

Shape Vs. Location

DESIGN: 2 x 2 factorial design. Pairs of stimuli identical or different in shape or location. Response: 'same' or 'different' according to task ('shape' or 'location').

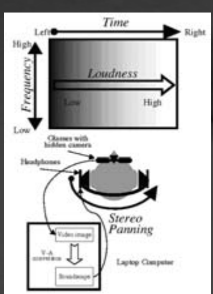




RESULTS: In a congenitally blind subject and proficient user of "The vOICe": soundscapes activated early auditory cortex to a similar extent regardless of task. Areas activated by the shape task: superior temporal sulcus and a variety of right hemisphere dominated visual areas. Areas activated for the location task: posterior parietal cortex and parieto-temporal-occipital junction.

CONCLUSIONS: Ventral visual stream is recruited to process shape information, while the dorsal visual stream contributes to location information in proficient blind users of "The vOICe" visuo-auditory substitution device.

"The vOICe" system

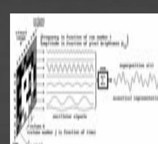


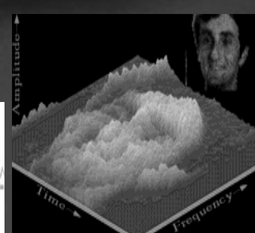
Encodes the different aspects of a visual scene (e.g. brightness and spatial location) using auditory information to create soundscapes. This is based upon 3 rules (Meijer, 1992):

1) The vertical axis is represented by frequency;

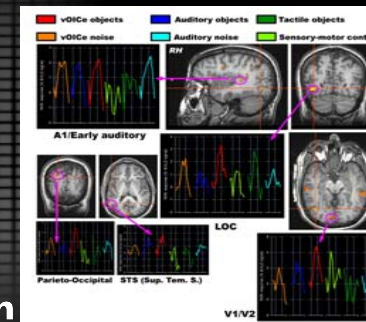
2) The horizontal axis is represented by time and stereo panning;

3) Brightness is encoded by loudness.





Object recognition



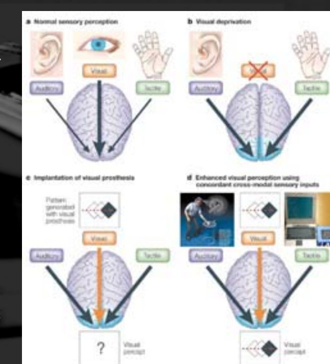
DESIGN: Tactile (palpation), auditory (e.g. typical sounds made by objects) and visual-to-auditory transformed objects (using visual objects encoded into soundscapes) and corresponding low-level sensory controls.

RESULTS: Areas activated by "The vOICe" objects included the STS and a constellation of right lateralized visual areas including occipito-temporal cortex (corresponding to LOC/LOtv complex, which is activated in sighted by vision and touch but not by audition: Amedi et al. 2002) and early 'visual' areas around the calcarine sulcus (V1/V2). Other clusters are found in the posterior parietal cortex, and STS.

CONCLUSIONS: Visual areas including V1 are recruited to process shape information acquired from "The vOICe". In addition we found activation of multisensory areas which are known to be involved in coordinate transformation and multisensory audio-visual integration. This activation pattern suggests that these areas may participate in transformation of the soundscapes into shape information.

Brain plasticity and sight restoration

(a) Under normal conditions, the occipital cortex receives predominantly visual inputs but perception is also highly influenced by cross-modal sensory information. (b) Following visual deprivation, neuroplastic changes occur such that the visual cortex is recruited to process sensory information from other senses. (c) After neuroplastic changes associated with vision loss have occurred, the visual cortex is fundamentally altered in terms of its sensory processing, so that simple re-introduction of visual input (by a visual prosthesis; orange arrow) is not sufficient to create meaningful vision. (d) To create meaningful visual percepts, a blind person can incorporate concordant information from remaining sensory sources. (Adapted from Merabet et al. 2005.)



CONCLUSIONS: SSD in general and "The vOICe" in particular might be useful to provide this concordant information. We demonstrate here a specific recruitment in blind users of "The vOICe" of ventral versus dorsal 'visual' stream activity for shape versus location using auditory input (including V1/V2) and convergence of object processing in visual cortex for "The vOICe", audition and touch.