The present study was designed to conduct a systematic mapping of the human visual cortex and to identify the visual nature of the stimulated cortex and provide the basis for the development of a cortical visual neuroprosthesis (Penfield et al. 1950, 1974; Brodkey et al. 1968, 1972; Dobelle et al. 1974, 1976, 2000; Bak et al. 1990, Schmidt et al., 1996. Normann et al. 1999, 2001). However, direct cortical stimulation requires occipital craniotomy and anesthesia, is usually restricted to patients with brain pathology requiring neurosurgical interventions, and has therefore limited utility for the investigation of the functional organization of human visual cortex.

Transcranial magnetic stimulation (TMS) is a noninvasive and relatively pain-free technique for cortical stimulation that has been applied with success in the study of motor and sensory physiology. TMS applied over the occipital cortex induces either visual suppression or direct cortical stimulation requires occipital craniotomy and anesthesia, is usually restricted to patients with brain pathology requiring neurosurgical interventions, and has therefore limited utility for the investigation of the functional organization of human visual cortex. Transcranial magnetic stimulation (TMS) is a noninvasive and relatively pain-free technique for cortical stimulation that has been applied with success in the study of motor and sensory physiology. TMS applied over the occipital cortex induces either visual suppression or direct cortical stimulation.

The present study was designed to conduct a systematic mapping of the human visual cortex by focal TMS in sighted and blind subjects.

Methods

TMS was delivered with a figure-of-eight coil (Cadwell Labs, Kennewick, WA, USA) to 28 positions arranged in a 2x2 cm grid over the occipital area. A frameless image-guided neuronavigation device (Brainsight 1.4, Rogue Research, Montreal, Canada) was used to describe the position of the actual sites of the stimulation coils relative to the cortical surface. A digitizing tablet connected to a PC computer running customized software, and audio and video recording were used for detailed and accurate data collection and analysis of evoked visual perceptions.

The protocol was applied on a group of 19 sighted and 15 legally blind volunteers. All gave their written informed consent prior to entering the study, which had been approved by the institutional review board.

Results

1. All subjects tolerated the procedure without complications. Specifically no seizure activity was induced by TMS.

2. Percentage of subjects perceiving phosphenes

3. Percentage of sampled positions able to elicit the perception of phosphenes

4. Characteristics of phosphenes in blind subjects

5. Preferential location of different types of visual perceptions induced by TMS in sighted subjects. Table size indicates number of phosphenes (see attached scales)

6. Examples of retinotopic mapping of TMS-induced phosphenes in blind subject #8

Conclusions

- TMS is able to reliably evoke phosphenes in all sighted subjects and in some proportion of blind subjects although not in all sampled positions, hence the relevance of a systematic mapping.
- Evoked perceptions were topographically organized. Despite minor inter-individual variations, the mapping results was reproducible and showed good congruence among different subjects.
- Phosphenes are subjective perceptions, and their descriptions are highly variable. This makes it necessary to build a protocol to analyze together the location of the stimulation, the region of the visual field activated and the evoked perception.
- TMS, in combination with other brain image technologies and methods, could be useful to improve our understanding of the physiologic organization and plastic changes in the brain of blind subjects as a consequence of their adaptation to the loss of sight. Such a non-invasive method could be used for the selection of suitable subjects for a cortical visual prosthesis.