

Short term light deprivation increases tactile spatial acuity in humans

Stefano Facchini, MD; and Salvatore M. Aglioti, MD

Abstract—The effect of short-term light deprivation on tactile spatial acuity was evaluated by asking 28 adult humans to perform a grating orientation task. The 14 subjects who were kept for 90 minutes in complete dark showed, immediately after deprivation, a reversible improvement of tactile spatial acuity. No acuity change was observed in the 14 nondeprived subjects. Results indicate that even a short-term visual deprivation may disclose highly dynamic plastic interactions between visual and tactile systems.

NEUROLOGY 2003;60:1998–1999

Animal and human studies suggest that deprivation of sensory stimuli brings about plastic effects not only within the same sensorimotor or visual modality but also across different modalities.¹ Studies in blind individuals, for example, show that the deprived visual cortex is recruited for performing tactile tasks.² Most visual deprivation studies in humans have been performed in conditions whereby sensory inputs were absent for long time. Only recently, a transcranial magnetic stimulation and fMRI study reported that significant changes in the function of visual cortical areas of healthy individuals were detectable following 45 minutes of visual deprivation.³ The present study assessed whether a visual deprivation period comparable to that used for demonstrating unimodal effects at physiologic level³ may also disclose cross-modal plasticity effects at a behavioral level.

Methods. We tested 28 healthy, right-handed volunteers. All were naive to the purpose of the experiment and did not have fingerpad calluses. The procedure was approved by the local ethical committee. Subjects performed the grating orientation (GO) task⁴ in three different sessions (I, II, III) separated by precise intervals (figure 1). Each subject was assigned to one of two experimental groups (deprived, “D”; nondeprived, “ND”), according to a randomization schedule. Subjects were blindfolded while performing the GO task. Only “D” subjects were visually deprived during the interval between sessions I and II. The experimental stimuli consisted of eight plastic plates with impressed parallel bars and grooves of equal width. The different bar/groove (gratings) widths used were as follows: 0.2, 0.4, 0.6, 0.9, 1.2, 1.5, 2.0, and 2.5 mm. The right hand of the subjects was fixated on a table in a palm-up position. Gratings were manually applied to the distal pad of the right index for about 1.5 seconds and with moderate force (resulting in about 2 to 3 mm of skin displacement). Previous reports showed that these grating stimuli can be delivered manually, performance being largely independent from subtle changes in time and pressure of application.^{4,6} The orientation of the gratings could be perpendicular or parallel to the long axis of the finger. On each trial, after the contact of the grating with the fingerpad, subjects had to report verbally whether the gratings were oriented perpendicularly or parallel. A forced-choice two-alternative procedure was used.

Each experimental session consisted of eight blocks, one for each bar width. Each block consisted of 20 trials, half with perpendicular and half with parallel gratings in a randomized order. The sequence of the blocks corresponded to a decreasing bar-width order. Percentage of correct responses was computed for each block and GO threshold was calculated by linear interpolation between bar widths spanning 75% correct responses.⁴ Care was taken to avoid any movement of the finger at the instant of contact with the gratings. No feedback about the correctness of the response was given to the subjects at any time. Each experimental session lasted about 20 minutes.

All subjects performed the GO task in a quasi-dark room, the residual environmental light being just enough for the experimenter to score the responses. Moreover, when performing the GO task sessions, all subjects wore a goggle mask with the visor completely obscured, which prevented subjects from being exposed to any source of light. It is worth emphasizing that “D” subjects kept the mask on from the beginning of session I to the end of session II. By contrast, “ND” subjects took the mask off and were re-exposed to light in the interval between end of session I and beginning of session II. All subjects were re-exposed to light between the end of session II and the beginning of session III. Based on the notion that consistent changes in visual cortex excitability appeared as early as 45 minutes, from the onset of visual deprivation, and disappeared within 120 minutes of reexposure to light,³ we submitted subjects to a GO task before, soon after a complete light deprivation of 90 minutes, and 130 minutes after the end of the light deprivation period (figure 1).

To avoid sleep or drowsiness during the deprivation period, subjects were kept alert by one examiner who remained in the room with the subject. Threshold values were entered in a mixed model analysis repeated-measures analysis of variance (ANOVA), with the Group (“D” and “ND”) as between-subjects factor and the session (I, II, III) as within-subject factor. Post hoc comparisons were carried out by using the Newman-Keuls test.

Results. No subject reported perception of any light during the GO task sessions or during the deprivation period. Moreover, no subject reported drowsiness during the deprivation period. GO threshold values are reported in figure 2.

The ANOVA showed the significance of the factor session ($F_{2,52} = 5.35$), GO threshold values being lower in session II than in sessions I and III. Relevant to the purposes of the present study is the Group X session interaction ($F_{2,52} = 3.67$, $p = 0.032$). Post hoc comparisons showed that the effect was entirely due to the lower threshold of the “D” group in session II than in session I ($p = 0.01$) and III ($p = 0.004$). No across-sessions changes were observed in the “ND” group.

From the Dipartimento di Scienze Neurologiche e della Visione (Dr. Facchini), Sezione di Fisiologia Umana, Università degli studi di Verona; and Dipartimento di Psicologia (Dr. Aglioti), Università di Roma “La Sapienza,” and Centro Ricerche di Neuropsicologia IRCCS Fondazione Santa Lucia, Rome, Italy.

Supported by the Human Frontier Science Program (RG 0161/1999-301B), Ministero Università e Ricerca, and Consiglio Nazionale delle Ricerche.

Received October 18, 2002. Accepted in final form February 21, 2003.

Address correspondence and reprint requests to Dr. Salvatore M. Aglioti, Dipartimento di Psicologia, Università di Roma “La Sapienza,” Via dei Marsi 78, 00185, Roma e IRCCS, Fondazione Santa Lucia, Via Ardeatina 306, 00185 Roma, Italy; e-mail: salvatoremaria.aglioti@uniroma1.it

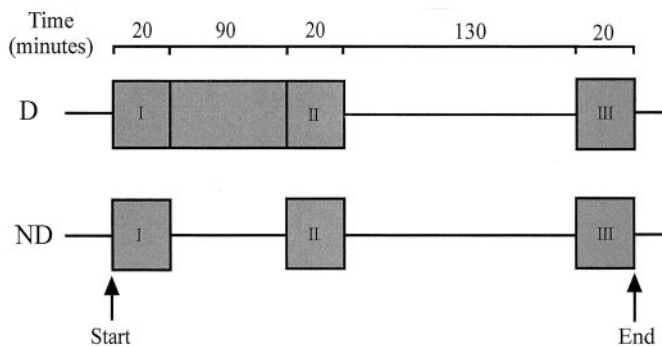


Figure 1. Sequence of experimental events in the deprived (“D”) and nondeprived (“ND”) groups. The two experimental groups resulted matched in age (D: 26 years, range 22 to 35; ND: 27.1 years, range 22 to 45), education (D: 16.4 years of school; ND: 16.3 years of school), and sex (D: 7 women; and ND: 6 women). Subjects belonging in the “ND” group were blindfolded with a goggle mask (gray areas) only for the duration of the three grating orientation (GO) sessions (I-II-III). The mask allowed full range of ocular movements as well as opening and closing of eyelids. By contrast, “D” subjects were blindfolded also in the 90 minutes between sessions I and II.

Discussion. The present study demonstrates that even a very short-term deprivation of light brings about an improvement of tactile spatial acuity. Indeed, in the light-deprived subjects threshold values decreased significantly in the GO session soon after the end of deprivation with respect to the session performed before light deprivation and the session performed about 2 hours after reexposure to light. This effect is linked to the period spent in complete dark, being absent in nondeprived subjects who performed the same number of GO sessions with the

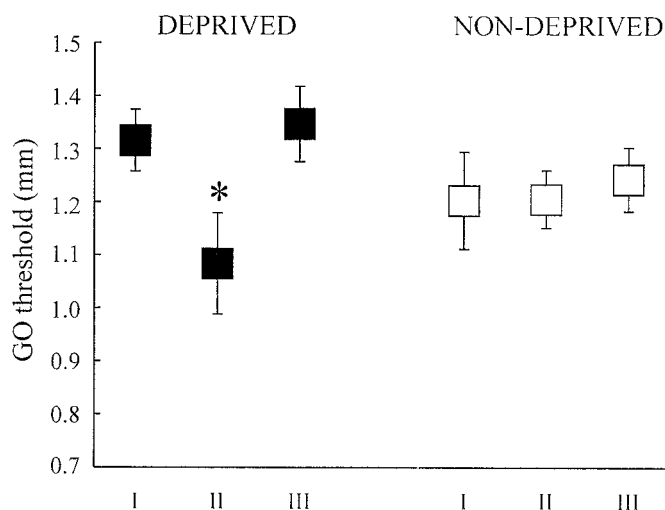


Figure 2. Grating orientation (GO) threshold values in the different sessions for the deprived (“D”) and nondeprived (“ND”) groups. GO threshold values are in mm (y axis). Note that although no GO threshold change was observed in the “ND” group, GO threshold values in session II are lower than in session I and III in the “D” group. * $p < 0.02$. Error bars are SEM.

same intervals from one another. Moreover, the effect is entirely reversible insofar as threshold values recorded 130 minutes after reexposure to light were comparable to predeprivation values. Relevant to the present results is the improvement of tactile acuity at one finger following acute deafferentation of the contralateral hand reported in a recent study⁷ that used an index of behavioral gain similar to that recorded in the present study. Moreover, the time course of our cross-modal effect may be comparable to that reported in the unimodal study.⁷

Studies in blind subjects provided physiologic and behavioral evidence that the deprived visual cortex is active during processing of nonvisual inputs.^{2,8,9} Thus, demonstrations of plastic changes and behavioral cross-modal gains related to visual deprivation in humans derive almost exclusively from long-term, nonreversible visual deafferentation studies. Tactile gains following reversible light deprivation have been reported only recently in a study in which normally sighted individuals showed an improvement of performance in a Braille character recognition task after 5 days of visual deprivation.¹⁰ This visual deprivation time window is reversible and much shorter than the average deprivation time used in the studies on cross-modal plasticity in blind subjects. Yet, it is still considerably longer than in our research. The duration of the deprivation window used in our study was chosen according to the notion that consistent changes in visual cortex excitability appear after 45 minutes of visual deprivation and disappear within 120 minutes of reexposure to light. Interestingly, our study suggests that unimodal⁷ and cross-modal short-term plastic effects may be disclosed by a comparable deprivation time window. The rapid and reversible improvement of tactile acuity found in the present study is most likely related to a dynamic and reversible cross-modal reassignment mechanism which, theoretically, can occur in the tactile or the visual system, or even in both systems.

References

- Shimojo S, Shams L. Sensory modalities are not separate modalities: plasticity and interactions. *Curr Opin Neurobiol* 2001;11:505–509.
- Cohen LG, Celnik P, Pascual-Leone A, et al. Functional relevance of cross-modal plasticity in the blind. *Nature* 1997;180–183.
- Borojerd B, Bushara KO, Corwell B, et al. Enhanced excitability of the human visual cortex induced by short-term light deprivation. *Cereb Cortex* 2000;10:529–534.
- Van Boven RW, Johnson KO. A psychophysical study of the mechanisms of sensory recovery following nerve injury in humans. *Brain* 1994;117(part 1):149–167.
- Johnson KO, Phillips JR. Tactile spatial resolution. I. Two-point discrimination, gap detection, grating resolution, and letter recognition. *J Neurophysiol* 1981;46:1177–1192.
- Vega-Bermudez F, Johnson KO. SA1 and RA receptive fields, response variability, and population responses mapped with a probe array. *J Neurophysiol* 1999;81:2701–2710.
- Werhahn KJ, Mortensen J, Van Boven RW, Zeuner KE, Cohen LG. Enhanced tactile spatial acuity and cortical processing during acute hand deafferentation. *Nat Neurosci* 2002;5:936–938.
- Uhl F, Franzen P, Lindinger G, Lang W, Deecke L. On the functionality of the visually deprived occipital cortex in early blind persons. *Neurosci Lett* 1991;124:256–259.
- Van Boven RW, Hamilton RH, Kauffman T, Keenan JP, Pascual-Leone A. Tactile spatial resolution in blind Braille readers. *Neurology* 2000; 54:2230–2236.
- Kauffman T, Theoret H, Pascual-Leone A. Braille character discrimination in blindfolded human subjects. *Neuroreport* 2002;13:571–574.