Haptic recognition memory following short-term visual deprivation: Behavioral and neural correlates from ERPs and alpha band oscillations

Gerardo Santaniello[a,*], Manuel Sebastián[a,b], Luis Carretié[c], Uxia Fernández-Folgueiras[a], José Antonio Hinojosa[a,d]

[a] Instituto Pluridisciplinar, Universidad Complutense de Madrid, 28040 Madrid, Spain
[b] Facultad de Ciencias de la Salud, Universidad Católica San Antonio de Murcia, 30107 Guadalupe, Murcia, Spain
[c] Facultad de Psicología, Universidad Autónoma de Madrid, 28049 Madrid, Spain
[d] Facultad de Psicología, Universidad Complutense de Madrid, 28223 Pozuelo de Alarcón, Madrid, Spain

ARTICLE INFO

ABSTRACT

In the current study, we investigated the effects of short-term visual deprivation (2 h) on a haptic recognition memory task with familiar objects. Behavioral data, as well as event-related potentials (ERPs) and induced event-related oscillations (EROs) were analyzed. At the behavioral level, deprived participants showed speeded reaction times to new stimuli. Analyses of ERPs indicated that starting from 1000 ms the recognition of old objects elicited enhanced positive amplitudes only for the visually deprived group. Visual deprivation also influenced EROs. In this sense, we observed reduced power in the lower-1 alpha band for the processing of new compared to old stimuli between 500 and 750 ms. Overall, our data showed improved haptic recognition memory after a short period of visual deprivation. These effects were thought to reflect a compensatory mechanism that might have developed as an adaptive strategy for dealing with the environment when visual information is not available.

1. Introduction

Brain plasticity effects following sensory deprivation rely on the activation of cross-modal silent pathways (Lazzouni & Lepore, 2014). This phenomenon is thought to account for the rapid changes observed after visual loss (Kupers & Ptito, 2014; Proulx, Brown, Pasqualotto, & Meijer, 2014; Ricciardi, Bonino, Pellegrini, & Pietrini, 2014). Evidence for this view comes from the results of several studies indicating that the occipital cortex is involved in the processing of auditory and tactile inputs after five days of visual deprivation (Merabet et al., 2008; Pascual-Leone & Hamilton, 2001).

Remarkably, effects of short-term visual plasticity have also been observed at shorter periods of blindfolding. For instance, prior studies have shown that 45 min of visual deprivation induced changes associated with the excitability of the occipital cortex, which resulted in lower thresholds for phosphenes perception in response to transcranial magnetic stimulation (Boroojerdi et al., 2000; Fierro et al., 2005). Similarly, in a fMRI study the activation of the occipital cortex was reduced when participants performed a tactile exploration of two-dimensional (2D) shapes following a two hours period of blindfolding (Weisser, Stilla, Peltier, Hu, & Sathian, 2005).

At a behavioral level, short-term visual deprivation has been found to improve tactile (Facchini & Aglioti, 2003; Weisser et al., 2005; but see Crabtree & Norman, 2014; Wong, Hackeman, Hurd, & Goldreich, 2011) and auditory perception (Landry, Shiller, & Champoux, 2013; Lewald, 2007). This compensatory mechanism may reflect an adaptive strategy for improving the recognition of our environment by enhancing the remaining senses once vision is lost or becomes inefficient (i.e., under extreme darkness).

An important aspect that deserves further consideration concerns the effects of the perceptual changes that follow short-term visual deprivation on subsequent memory processes, given prior reports showing better performance in tactile recognition memory in long-term deprived blind children (D'Angiulli & Waraich, 2002). In the present electroencephalographic (EEG) study, we aimed to address this question by investigating haptic recognition memory for familiar objects following a 2 h interval of visual deprivation in adults. Event-related potentials (ERPs) and time-frequency activity (event-related oscillations, or EROs) were analyzed for this purpose. Prior work from behavioral studies on recognition memory in the haptic modality with non-deprived participants showed that the subsequent recognition of a repeated stimulus elicits shorter reaction times (Ballesteros, Reales, & Manga, 1999;

Craddock & Lawson, 2008; Sebastian, Reales, & Ballesteros, 2011). Also, the results of previous ERP studies on haptic old/new recognition judgments indicate that the correct identification of old compared to new stimuli elicits enhanced amplitudes in a positive component between 550 and 750 ms (Sebastian et al., 2011) with a wide distribution over the scalp and with highest amplitudes at parietal regions. This result is in line with the proposals made by the double process theory (see Rugg & Curran, 2007, for a review), which claims that old-new tasks elicit two qualitative different components. The first component peaks between 300 and 500 ms in fronto-central electrodes and has been associated with familiarity processes (Curran, 2000; Paller, Voss, & Boehm, 2007; Rugg, Mark et al., 1998). The second component peaks between 400 and 800 ms in parietal electrodes and has been related to deeper processes involved in episodic retrieval such as explicit recognition and recollection (Curran, 2000; Rugg, Schloerscheidt, & Mark, 1998). In line with this evidence, Sebastian et al. (2011) interpreted their findings as an index of the involvement of recollection processes in haptic memory.

Old/new effects in haptic recognition memory have also been associated with modulations in brain oscillations. In particular, alpha power decrements have been observed in haptic recognition memory tasks between 400–600 ms following the presentation of the old stimulus and with a wide distribution over the scalp (Sebastian et al., 2011). Remarkably, these effects have also been observed during the haptic processing of familiar objects. In this sense, upper alpha band power (10–12 Hz) has been shown to decrease over time as confidence in object recognition increases (Martinovic, Lawson, & Craddock, 2012). Conversely, an increase in the spectral power of the upper alpha band has been found between 1250 and 1750 ms over bilateral anterior, central and posterior regions during the processing of haptically primed stimuli (Sebastian & Ballesteros, 2012). Interestingly, this upper alpha effect was interpreted to reflect the access to explicit processes related to semantic memory (Sebastian & Ballesteros, 2012). Overall, prior data suggests that the alpha band may be involved in stimulus retrieval during haptic recognition. Additionally, the analysis of lower alpha frequency (including sub-bands of lower-1 and lower-2) in haptic memory studies has revealed that activity in this band might also be modulated by attentional demands (Sebastian & Ballesteros, 2012; Sebastian et al., 2011). Finally, the results of long-term visual deprivation studies suggest a possible link between alpha reductions and modulations in inhibitory processes in visually deprived participants (Hawellek et al., 2013; Kriegseis, Hennighausen, Rosler, & Roder, 2006). Interestingly, these effects have been related to increased activation of the occipital cortex. According to the compensation hypothesis (see Kupers & Ptito, 2014, for a review), these effects may reflect the involvement of silent connections which are recruited to deal with the visual loss (Pascual-Leone & Hamilton, 2001).

To the best of our knowledge, the impact of visual deprivation on recognition memory with EEG measures remains unexplored. As far as we know, only one prior study in the auditory modality (Roder, Rosler, & Neville, 2001) recorded ERPs to compare memory performance between sighted and blind participants. This study found larger old-new amplitude differences for the blind group in a late component starting from approximately 1000 ms. These results were interpreted to reflect a more efficient use of retrieval strategies in blind participants (Roder et al., 2001). Considering these results and based on prior reports of improved tactile memory performance in behavioral studies examining long-term visual deprivation (D'Angiulli & Waraich, 2002; Davidson, Barnes, & Mullen, 1974), we expect that visual deprivation would facilitate haptic recognition memory. In particular, we predict faster reaction times and larger amplitudes in a late-latency positive component during the correct identification of old/new stimuli in the deprived compared to the non-deprived group. Furthermore, in line with prior EROs data (Sebastian & Ballesteros, 2012; Sebastian et al., 2011), we expect that repeated stimuli should be associated with increased activity in upper alpha bands (1250–1750 ms). Again, we hypothesize

larger differences between the old/new stimuli in the visual deprived participants compared to the control group. Additionally, decreased power activity in the alpha band around 400–600 ms could be expected following the presentation of the old stimuli in the visually deprived group. Finally, we also hypothesize modulations in the lower bands of alpha, as consequence of the shift of attentional resources in visually deprived participants.

2. Methods

2.1. Participants

Thirty-eight right-handed volunteers with no history of neurological disorders were recruited for this study (M = 21.9; SD = 2.9; range = 20–32). They were randomly assigned to an experimental (deprived of vision) and a control (not deprived) condition. The deprived group was composed by 11 women and 8 men, whose mean age was 22 years old (SD = 2.8; range = 20–29), whereas the control group consisted of 12 women and 7 men, with a mean age of 21.9 years (SD = 3.2; range = 20–32). All participants signed an informed consent form before starting the experiment, which was carried out according to the recommendations of the Declaration of Helsinki (1964).

2.2. Materials

Stimuli had previously been selected according to their familiarity values in our laboratory through a pilot study (N = 18). The pilot consisted of a naming task where participants had to identify the 192 familiar objects they were haptically exploring. They were blindfolded throughout the exploration phase. After the pilot we retained 96 familiar objects as stimuli for the haptic task based on its successful identification rate. Seventy-two out of these 96 selected objects were used as experimental stimuli and 24 as fillers with the purpose of randomizing the sequences for the presentation of objects. Ten additional objects were selected for practice trials. All stimuli belonged to basic level categories such as tools, domestic utensils, objects of personal hygiene, etc. Their shape and size allowed the participants to make/perform the exploratory movement of enclosure (Lederman & Klatzky, 1987), crucial to our purposes as explained later. None of the stimuli produced any special sound or smell allowing recognition.

The experimental setting is schematically illustrated in Fig. 1A. The desk where participants performed the task included a monitor connected to a computer and two speakers located behind it. Objects were placed on an adjustable force-sensitive board located at the center of the platform. This piezoelectric board was interfaced to the presentation and recording computers, and sent triggers whenever participants touched an object, marking out the beginning of the exploration phase. Old/new responses were collected through two foot-pedals placed under the platform. The assignment of this dual response to both pedals was counterbalanced across participants and groups.

2.3. Procedure of visual deprivation

Before entering in the recording chamber, participants moved to a pre-test room and wore an electrodes' cap. In order to prevent any exposure to the light, the blindfold was accomplished through a sleeping mask, which was placed below an obscured swimming goggle, covered with black tape to make it opaque. Finally, the blindfold was adjusted to the participant's face using a medical tape to occlude any possible residual groove between the participant's face and the goggles (see Fig. 1B). A similar blindfolding procedure has been used in prior studies (Crabtree & Norman, 2014; Kauffman, Theoret, & Pascual-Leone, 2002; Merabet et al., 2008) since it allowed the participants to blink and to make more natural eye movements. After the blindfolding and prior to the start of the experiment, participants were exposed to a 12V–50W source of light directed to their face via a flexible hose. The