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

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## 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.

*Keywords* Short-term visual deprivation, Haptic memory, Recognition memory, ERPs, Induced oscillations

## 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 phosphene 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, Hackman, 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, & PascualLeone, 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 room light remained off to create a greater luminosity contrast, and participants had to indicate any light changes they perceived. This proof was used to ensure that participants were unable to perceive any source of brightness and to eventually adjust the blindfold to the participant's face. Its duration lasted 1–2 min approximately. Participants from both groups stayed in the pre-test room for 80 min holding a conversation with the experimenter and responding to a verbal questionnaire about music. This procedure was used in order to keep them awake during this phase (following the procedure used by Weisser et al., 2005). Only the visually deprived group was dressing the blindfold, so it performed this task in visual deprivation, whereas participants in the control group were in normal view and room light conditions. After this period, all participants were conducted to the recording chamber and took seat. For the deprived group, the remaining 40 min needed to achieve the 2 h' visual deprivation were spent in electrode placement. Participants in the control group were blindfolded immediately prior to start the task so they also performed the haptic task in visual deprivation. Thereafter, both groups began the haptic task (see below).

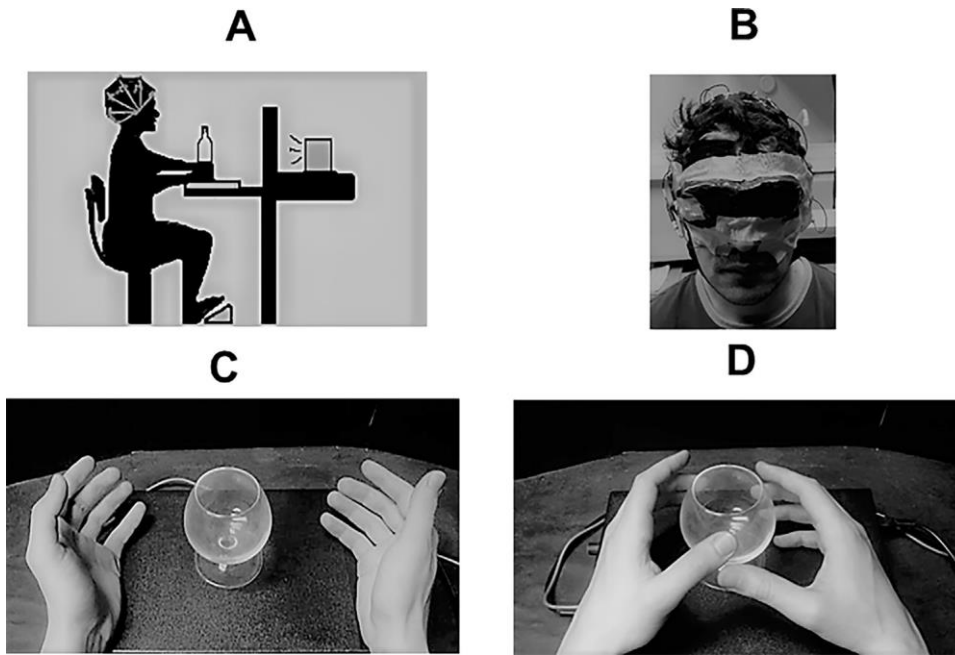


Fig. 1. Illustration of the experimental setting during the haptic recognition task (A). Example of the blindfold employed to visually deprive the participants (B). Exploratory movement of enclosure before (C) and during the haptic exploration (D).

#### 2.4. Procedure

The haptic task consisted of old/new recognition judgments in a continuous presentation paradigm. Objects were randomly divided into two blocks of 36 stimuli. Each object was presented twice during the experimental session, the first time as a new stimulus and the second time as an old stimulus. In addition, there were 12 fillers in each block that were not repeated. These fillers were not included in the analyses, but their presentation was necessary to ensure an adequate pseudorandom sequence, as explained later. The experimental design included two conditions: first presentation of an object (new condition) and second presentation of the same object (old condition). Objects were presented in a pseudo-random sequence in which old stimuli could appear immediately after their first presentation as new objects (LAG 0), after the presentation of another intervening object (LAG 1) or after the successive presentation of four objects (LAG 4). The order of presentation was based on four fixed sequences of 7 items (three new objects, three old and one filler), each of them including a LAG 0 presentation, LAG 1 presentation and a LAG 4 presentation (see [Table 1](#)). Each block was composed by a random presentation of the four sequences on three occasions, for a total of 12 sequences. The use of fixed sequences allows to a priori control the distribution of the different types of objects (old or new stimuli), avoiding the effects of expectancy that might be encountered using a simple randomization system in which the first objects of each sequence would tend to be new.

Table 1

Sequence of objects presentation

SEQUENCE	ORDER OF PRESENTATION					
	1	3	4	5	6	7
	2					
A	N1L1	O1 L1	N3L0	O3 L0	FILLE R	O2 L4
	N2L4					
B	N1L4	N2 L0	O2L0	N3 L1	O1L4	O3 L1
	FILLER					
C	N1L1	O1 L1	FILLE R	N3 L0	O3L0	O2 L4
	N2L4					
D	N1L4	O2 L0	FILLE R	N3 L1	O1L4	O3 L1
	N2L0					

Sequences (A B C D) and order of presentation (1 2 3 4 5 6 7) of the objects. N= new; O =old; L = LAG (e.g.: N1L4 = new object number 1, lag 4; O1L4 =old object number 1, lag 4).

A trial had the following sequence. The experimenter first placed an object on the force-sensitive board. Thereafter, participants opened their hands and positioned them next to the sensor in order to make the exploratory movement of enclosure (Fig. 1C). The trial began with an acoustic signal (1 s) indicating the beginning of the exploration stage. Subsequently, participants were allowed to explore the object with both of their hands (Fig. 1D) and had to judge whether the stimulus was a new or a repeated (old) object. They responded by pressing one of the two pedals for new objects and the other for old stimuli. As indicated, pedals were counterbalanced across groups and participants. Although participants were explicitly instructed to respond as soon and accurately as possible, there was no specific time limit for objects' exploration. After giving a response, participants moved back their hands to the initial position and the experimenter replaced the object on the force-sensitive sensor. The experiment consisted of a total of 168 trials. The task was programmed with the stimulus presentation E-Prime 2.0 software ([Psychology Software Tools, Pittsburgh, PA](#)). Prior to the start of the experiment, a ten trials practice block was presented to participants. In addition, a break of five minutes between the two blocks of trials was allowed. Objects were in the same orientation both in the new and the repeated presentation, and participants were not allowed to rotate or lift them from the piezoelectric board.

After completing the haptic task, the blindfold was removed and all participants had five minutes to perform a free-recall task consisting in writing down, on a sheet of paper, the name of all the objects they remembered to have explored, with the exception of the practice trials. Subsequently, both groups performed a verbal recognition task to estimate how many objects were actually recognized. The experimenter presented therefore a list of 192 names of familiar objects, including the 96 presented during



the haptic task. Participants indicated those they thought to have touched. This task did not have a time limit.

## 2.5. EEG data recording

The electroencephalographic activity was recorded using an adjustable 64 electrodes cap (Quick-Cap, Neuroscan, Inc., USA), with Ag/AgCl small size electrodes (50–53 mm) distributed according to the international system 10–20 ([“American Electroencephalographic Society guidelines for standard electrode position nomenclature,” 1991](#)). The 62 active electrodes were: O2, O1, OZ, PZ, P4, CP4, P8, C4, TP8, T8, P7, P3, CP3, CPZ, CZ, FC4, FT8, TP7, C3, FCZ, FZ, F4, F8, T7, FT7, FC3, F3, FP2, F7, FP1, PO5, PO3, P1, POZ, P2, PO4, CP2, P6, PO6, CP6, C6, PO8, PO7, P5, CP5, CP1, C1, C2, FC2, FC6, C5, FC1, F2, F6, FC5, F1, BF4, AF8, F5, AF7, AF3, FPZ. All electrodes were online referenced to the average of the mastoids. The electrooculographic activity was recorded using vertical (VEOG) and horizontal (HEOG) bipolar electrodes placed at supra-infraorbital level of the left eye and on the outer canthus of both eyes respectively. Data were continuously recorded with a SynAmps (Neuroscan, Inc.) amplifier and filtered through a 0.1–100 Hz online band-pass filter. The signal was digitized with a sampling rate of 1000 Hz and the impedance kept below 15 k $\Omega$ . Participants were asked to avoid sudden muscle movements, changes of posture, jaw clenching or lateral eyes movements.

## 2.6. Data analysis

All data were analyzed with the statistical program IBM SPSS, version 20. Whenever the sphericity was violated, we applied the [Greenhouse and Geisser \(1959\)](#) epsilon ( $\epsilon$ ) correction for degrees of freedom of the within-subject measures. Significant effects of the interactions were further explored with planned pairwise comparisons. All these contrasts were corrected for multiple comparisons by means of the Bonferroni procedure ( $\alpha = 0.05$ ). According to [Picton et al. \(2000\)](#), uncorrected degrees of freedom, epsilon values and corrected  $p$  are reported.

### *2.6.1. Behavioral analysis*

Mean reaction times to correct trials and accuracy were analyzed for each participant using a mixed factorial design (repeated measures ANOVA) with a two levels within-subjects factor (Presentation: first, second) and a two levels between-subjects factor (Group: deprived, control). As regards reaction times, trials shorter than 150 ms ( $n = 17$ ) were excluded from the analysis. In addition, scores outside 3 deviations from the inter-quartile range were considered outlier responses ( $n = 36$ ) and were not included in the analysis. Therefore, an analysis was conducted over a total of 4978 valid trials, on average 65.1 trials in the new ( $SD = 4.6$ ; range = 53–72) and 64.5 trials in the old condition ( $SD = 4.7$ ; range = 55–72) in the deprived group and 66.7 ( $SD = 3.1$ ; range = 57–70) in the new and 65.6 trials ( $SD = 4.6$ ; range = 56–71) in the old condition for the control group.

With respect to accuracy, the mean percentage of errors was submitted to the ANOVA after excluding the invalid trials due to technical errors and reaction times faster than 150 ms. Data analyses in the free recall and verbal recognition task were conducted on a two levels factor (Group: deprived, control) with a univariate ANOVA.



### 2.6.2. EEG data preprocessing

Raw EEG data were processed with EEGLAB, version 12.01 (Brunner, Delorme, & Makeig, 2013), a toolbox implemented in the MATLAB environment (The MathWorks, Inc.). First, intervals corresponding to trials with errors, outliers' responses and technical failures were eliminated from the EEG continuous data. Then, the sampling rate was reduced to 500 Hz and data were visually inspected to remove gross artifacts. Subsequently we applied a digital FIR filter (0.1–30 Hz, 12 dB/Oct. roll-off). Thereafter high frequency noise or saturated activity channels (< 10%) were interpolated ( $M = 0.26$ ;  $SD = 0.64$ ) according to the Spline method, with a 10% limit of the entire set of channels. The average number of channels interpolated was 0.32 ( $SD = 0.67$ ) for the deprived group and 0.22 ( $SD = 0.63$ ) for the control group. Data were then submitted to an infomax independent components analysis (Makeig, Jung, Bell, Ghahremani, & Sejnowski, 1997) to eliminate the residual high frequency noise, blinks activity, muscle movements and heart activity (Jung, Makeig, Humphries et al., 2000). Before the artifacts rejection, the continuous set of data was segmented in –1000 to 2000 ms epochs and adjusted to the baseline activity (ms –1000 to 0) through the ERPLAB plugin (Lopez-Calderon & Luck, 2014). Artifactual independent components were removed following the visual inspection of their scalp maps, power spectra, ERP-image plot and the components scroll (Jung, Makeig, Humphries et al., 2000; Jung, Makeig, Westerfield et al., 2000). Finally, epochs were visually inspected to remove those that were still contaminated by artifacts. This method led us to retain a grand average of 58.8 trials in the new ( $SD = 6.2$ ; range = 46–68) and 57.8 trials in the old condition ( $SD = 6.7$ ; range = 44–68) in the deprived group and 62.3 ( $SD = 4.8$ ; range = 51–69) in the new and 61.3 trials ( $SD = 7$ ; range = 42–71) in the old condition for the control group.

*2.6.2.1. Scalp ERP analysis.* In order to identify task-related components, we performed a Principal Components Analysis (PCA). The PCA has proven to be a reliable data-driven method to define the components shaping an ERP waveform (Chapman & McCrary, 1995; Dien, Beal, & Berg, 2005). The theoretical assumption underlying the PCA is based on the fact that values from time-points forming each component tend to covary, but are unrelated to time-points belonging to other components. Among PCA outputs, factor scores are especially relevant since they are directly related to amplitudes and may be submitted to statistical contrasts. Additionally, the use of the PCA for the analyses of the ERPs becomes a very useful tool in high-density electrode arrays. In fact, this method allows for a reliable identification of ERP components. Remarkably, PCA is particularly useful when data can be noisy due to movement artifacts as it is the case of haptic studies. Finally, even if the PCA has not previously been used in the haptic modality, it has been successfully used in recognition memory studies (e.g. Curran & Dien, 2003). The PCA was performed through the ERP PCA toolkit (Dien, 2010a) and conducted across all participants, over a time range of 3 s (the entire epoch) and including all the 62 active electrodes. First, we conducted a temporal PCA (tPCA) to define and quantify temporal ERP components. The Promax system was used (Dien, 2010b) for the factor rotation. The rotation parameter was set at three. The decision about the number of components to retain was based on the results of the parallel test, as described in Dien (2012). Once quantified in temporal terms, temporal factor scores were submitted to a spatial PCA (sPCA) in order to decompose the scalp topography corresponding to each temporal factor. Whereas tPCA separates ERP components along time, sPCA distinguishes ERP components along space, with each spatial factor ideally reflecting one of the concurrent neural processes underlying each temporal factor. This spatial decomposition is an advisable strategy prior to statistical contrast, because ERP components frequently behave differently in some scalp areas than they do in others (e.g., they present opposite polarity or react differently to experimental manipulations). Basically, each region or spatial factor is formed with the scalp points where recordings tend to covary. As a result, the shape of the sPCA-configured regions is functionally based, and scarcely resembles the shape of the geometrically configured

regions defined by traditional procedures. Following the recommendation of [Dien \(2012\)](#), retained factors were submitted to an Infomax rotation with the rotation parameter set again at three. The experimental effects on spatial factor scores were finally analyzed via mixed (or split-plot) ANOVA with a two level (Presentation: first, second) within-subjects factor and a two levels (Group: deprived, controls) between-subjects factor.

*2.6.2.2. Induced activity analysis.* Since PCA has not extensively been used in the time-frequency domain, we followed a region of interest approach (ROIs) for EEG analyses, which has been used in many prior studies (e.g. [Schneider, Lorenz, Senkowski, & Engel, 2011](#)). Electrodes were grouped into the following regions of interest (ROIs): left anterior (LA) [F5 F3, F1, FC5, FC3, FC1], right anterior (RA) [F2, F4, F6, FC2, FC4, FC6], left Central (LC) [C5, C3, C1, CP5, CP3, CP1], right central (RC) [C2, C4, C6, CP2, CP4, CP6], left posterior (LP) [P5, P3, P1, PO5, PO3, O1], right posterior (RP) [P2, P4, P6, PO4, PO6, O2]. Our decision to select these ROIs was based on prior haptic studies showing that memory effects in this modality are distributed over the entire scalp ([Sebastian & Ballesteros, 2012](#); [Sebastian et al., 2011](#)). Induced activity was extracted from the EEG signal through the Complex Morlet wavelet method, using the ERPWAVELAB software ([Morup, Hansen, & Arnfred, 2007](#)). The Morlet wavelet is obtained by applying a Gaussian distribution to the sinusoidal waves. This method improves the balance between temporal precision and accuracy in frequency. The function was applied for each electrode over an epoch of -1000 to 2000 ms with a resolution of 2 ms for each time point (500 Hz sampling rate). The wavelet had a central frequency = 1 and a bandwidth = 1 ([Herrmann, Mecklinger, & Pfeifer, 1999](#); see [Sebastian & Ballesteros, 2012](#), for a description of the method). The width was of 6.28 oscillations, over a total of 4560 epochs (2349 for the control group and 2211 for the experimental group). Although based on prior literature our focus was on the alpha band, we analyzed the range of frequencies between 1 and 30 Hz. These frequencies were divided into 100 spaces with an interval of 0.3 Hz. Post-stimulus activity was normalized with respect to the baseline period between -500 and -250 ms ([Sebastian & Ballesteros, 2012](#)) to eliminate potential artifacts generated at the edges of the epochs during the process of decomposition. The peak of the individual alpha frequency amplitude (IAF) was then calculated for each of the participants. This value is considered the cut-point between the upper alpha and lower-2 alpha frequencies ([Klimesch, Russegger, Doppelmayr, & Pachinger, 1998](#)). In addition, following the method proposed by [Doppelmayr, Klimesch, Pachinger, and Ripper \(1998\)](#), the width of the bands was estimated individually following the rule of the 20% of the IAF value. This procedure of adjusting the signal individually avoids that transition frequency bands –such as alpha and theta, which present an opposite pattern of activity in a given task- will tend to cancel each other ([Klimesch et al., 1998](#)). Thus, we obtained the induced activity, adjusted to the individual alpha frequency of each participant. The averaged IAFs led us to extract the following bands: lower-1 alpha (5.7–7.6 Hz), lower-2 alpha (7.6–9.5 Hz) and upper alpha (9.5–11.4 Hz) for the visual deprived group and lower-1 alpha (5.6–7.5 Hz), lower-2 alpha (7.5–9.4 Hz) and upper alpha (9.4–11.3 Hz) for the control group. These bands were used as ranges for the analysis of the old/new conditions. Finally, epochs were segmented in eight consecutive time-windows of 250 ms for further analysis ([Sebastian & Ballesteros, 2012](#)).

Time-frequency data were analyzed with a mixed factorial design including a two levels (Presentation: first, second) and a six levels (ROI: LA, RA, LC, RC, LP, RP) intra-subjects factor, and a two levels (Group: deprived, controls) inter-subjects factor. Time-frequency values were submitted to a repeated measures analysis of covariance (ANCOVA) in which the maximum power of the alpha band was introduced as a covariate.

### 3. Results

#### 3.1. Behavior

##### 3.1.1. Exploration times

The main effect of Presentation was significant [ $F(1,36) = 156.857$ ;  $p < 0.001$ ;  $\eta^2_p = 0.813$ ], showing that the exploration times for new objects (mean or  $M = 2378.2$  ms, standard deviation or  $SD = 902.7$  ms) were longer than those for old objects ( $M = 1437.5$  ms,  $SD = 538.3$  ms) in both groups (average difference =  $940.72$ , 95% confidence interval or  $CI [788.39, 1093.05]$ ). The Presentation x Group interaction was also significant [ $F(1,36) = 8.844$ ;  $p = 0.005$ ;  $\eta^2_p = 0.197$ ]. The post-hoc analysis revealed that visually deprived participants were faster ( $M = 2062$  ms,  $SD = 551.9$  ms) than controls ( $M = 2694.4$  ms,  $SD = 1076.7$  ms) to explore new objects ( $p = 0.029$ ). In contrast, only a statistical trend was found for the main effect of Group [ $F(1,36) = 3.479$ ;  $p = 0.07$ ;  $\eta^2_p = 0.088$ ], showing that once the old-new conditions were collapsed, the visually deprived ( $M = 1703.3$  ms) were no longer significantly faster than the control group ( $M = 2112.3$  ms).

##### 3.1.2. Accuracy

The mean percentage of errors was  $2.44$ ,  $SD = 1.67\%$  (sum of errors or  $n = 31$ ; range of errors =  $0-4$ ) for new and  $3$ ,  $SD = 2.81\%$  ( $n = 39$ ; range =  $0-7$ ) for old objects in the visually deprived group and  $2.14$ ,  $SD = 1.75\%$  ( $n = 28$ ; range =  $0-4$ ) for new and of  $2.1$ ,  $SD = 2.01\%$  ( $n = 27$ ; range =  $0-4$ ) for old objects in the control group. We found no significant effects of Presentation [ $F(1,36) = 0.332$ ;  $p = 0.568$ ;  $\eta^2_p = 0.009$ ], Group [ $F(1,36) = 1.555$ ;  $p = 0.221$ ;  $\eta^2_p = 0.041$ ] or for the Presentation x Group interaction [ $F(1,36) = 0.434$ ;  $p = 0.514$ ;  $\eta^2_p = 0.012$ ].

##### 3.1.3. Free recall task and verbal recognition task

The mean percentage of the remembered objects-related words in the free recall task was  $30.26$ ,  $SD = 6.22\%$  (range of remembered words =  $11-30$ ) in the visually deprived group and  $29.44$ ,  $SD = 6.63\%$  (range =  $13-32$ ) in the control group. In the verbal recognition task, the mean percentage of hits was  $77.41$ ,  $SD = 11.49\%$  (range =  $32-67$ ) in the deprived group and  $78.5$ ,  $SD = 12.82\%$  (range =  $33-68$ ) in the control group. The univariate ANOVAs showed no significant differences in either the recall [ $F(1,36) = 0.154$ ;  $p = 0.697$ ;  $\eta^2_p = 0.004$ ] or the recognition tasks [ $F(1,36) = 0.073$ ;  $p = 0.788$ ;  $\eta^2_p = 0.002$ ], indicating similar performances in the two groups.

#### 3.2. ERPs

Eleven temporal factors were extracted by the tPCA (see 2.6.3. and Fig. 2). Two of them were especially relevant to our purposes according to previous literature (Roder et al., 2001; Sebastian et al., 2011): a late positive component (LPC) peaking around  $450$  ms and a slow-wave potential (SW) which peaked around  $1370$  ms. The amount of total variance explained by each of these two temporal factors was  $0.6285\%$  (factor variance  $0.9105$ ) for the SW and  $0.0254\%$  (factor variance  $0.9155$ ) for the LPC components. For each of these two temporal factors, we extracted one major spatial region as the result of the parallel test. The ANOVAs were conducted on the LPC and SW spatial factor scores, directly related to amplitudes, as already explained. The results of the analyses are summarized in Table 2 (only significant effects will be described in the main text).

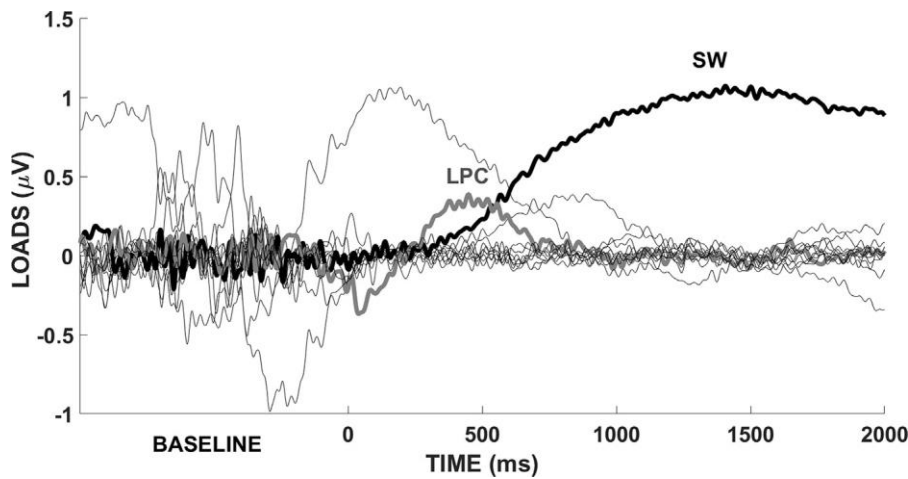


Fig. 2. Temporal principal component analysis (tPCA): factor loads graph showing the two components extracted after the Promax rotation. LPC, late positive component; SW, slow wave. TF: temporal factor.

Table 2  
Results of the PCA analysis.

COMPONENT	LPC	SW
PEAK (RANGE)	446 ms (250– 700)	1370 ms (300– 2000)
FACTOR	Centro- Posterior	Centro- Posterior
P	5.403*	0.850
G	0.096	0.030
PxG	2.138	5.048*

F values (df. 1, 36) are shown. Asterisks indicate the level of significance: P =Presentation; G= Group; Px G= Presentation x Group. SW: slow wave, LPC: late positive component. \* $p < 0.05$ .

The main effect of Presentation was significant over a centro-posterior LPC spatial factor [ $F(1,36) = 5.403$ ;  $p = 0.026$ ;  $\eta^2_p = 0.130$ ] (average difference = 410, 95% CI [0.052, 0.767]). Larger positive amplitudes were observed following the presentation of old objects (see Fig. 3). In addition, a Presentation x Group interaction was observed in a centro-posterior SW spatial factor [ $F(1,36) = 5.048$ ;  $p = 0.031$ ;  $\eta^2_p = 0.123$ ]. The results of the post-hoc analyses revealed a significant difference between old and new stimuli only in the visually deprived group ( $p = 0.031$ ). Old objects elicited more positive amplitudes compared to new objects (see Fig. 4).

### 3.3. EROs

A summary of all the results is shown in Tables 3–9 (only significant effects will be described in the main text). The covariable IAF adjusted scores in lower alpha-1 (0–250 and 1750–2000 ms), lower alpha-2 (0–2000 ms) and upper alpha (0–2000 ms). Covariates are evaluated at the IAF mean value (1.0643  $\mu V$ ). Although the scope of this work was to examine modulations in the alpha bands, recognition memory effects in other bands were also investigated. However, none of these analyses reached statistical significance (all  $ps > 0.05$ ).

### 3.3.1. Group effects

The main effect of Group was significant in the lower-2 alpha band in the baseline [ $F(1, 35) = 8.226$ ;  $p = 0.007$ ;  $\eta^2_p = 0.190$ ] (average difference  $= -0.031 \mu V$ , 95% CI  $[-0.053 \mu V, -0.009 \mu V]$ ), where the visually deprived group showed a reduced mean power ( $M = 0.87 \mu V$ ) compared to the control group ( $M = 0.90 \mu V$ ). Similarly, the main effect of Group was also significant in the upper alpha frequency in the baseline [ $F(1,35) = 4.529$ ;  $p = 0.040$ ;  $\eta^2_p = 0.115$ ] (average difference  $= -0.028 \mu V$ , 95% CI  $[-0.055 \mu V, -0.001 \mu V]$ ). Once again, a lower mean power was observed in the group of visually deprived participants ( $M = 0.87 \mu V$ ) compared to the controls ( $M = 0.90 \mu V$ ).

### 3.3.2. Interactions

In the lower-1 alpha frequency, we observed a significant effect of Presentation [ $F(1,35) = 4.962$ ;  $p = 0.032$ ;  $\eta^2_p = 0.124$ ] (average difference  $= -0.024 \mu V$ , 95% CI  $[-0.066 \mu V, 0.018 \mu V]$ ) and a Presentation x ROIs x Group interaction in the 500–750 ms temporal frame [ $F(5175) = 3.286$ ;  $p = 0.032$ ;  $\eta^2_p = 0.086$ ]. Results from pairwise comparisons indicated that in both the LA and the RA ROIs ( $p = 0.044$ ;  $p = 0.016$ ), the deprived group showed lower power for new ( $M = 1.03 \mu V$ ;  $M = 1.01 \mu V$ ) compared to old stimuli ( $M = 1.10 \mu V$ ;  $M = 1.11 \mu V$ ).

In the lower-2 alpha frequency, a significant Presentation x ROIs x Group interaction was observed in the temporal window between 250 and 500 ms [ $F(5175) = 2.877$ ;  $p = 0.045$ ;  $\eta^2_p = 0.076$ ]. Pairwise comparisons revealed that in the LA ROI the control group showed ( $p = 0.018$ ) lower power for old stimuli ( $M = 0.951 \mu V$ ) compared to new stimuli ( $M = 1.03 \mu V$ ). Also, we found a significant Presentation x ROIs x Group interaction in the 750–1000 ms temporal frame [ $F(5175) = 3.089$ ;  $p = 0.034$ ;  $\eta^2_p = 0.081$ ]. The results of pairwise comparisons revealed that new stimuli were associated with lower power compared to old stimuli. For the visually deprived group significant results were found in the following ROIs: LA ( $p = 0.027$ ), RA ( $p = 0.005$ ), LC ( $p = 0.024$ ), RC ( $p = 0.005$ ) and LP ( $p = 0.028$ ). Significant effects for the control group were only found in the LP ROI ( $p = 0.026$ ).

In the upper alpha frequency, the ANCOVA showed a significant Presentation x ROIs x Group interaction [ $F(5175) = 3.923$ ;  $p = 0.020$ ;  $\eta^2_p = 0.101$ ] between 1250 and 1500 ms. The results of pairwise comparisons revealed that new stimuli were associated to lower power compared to old stimuli. For the deprived group, significant effects were observed in the following ROIs: LA ( $p = 0.029$ ), RA ( $p = 0.016$ ), LC ( $p = 0.044$ ), whereas in the control group we found significant effects in the following ROIs: LA ( $p = 0.012$ ), RA ( $p = 0.026$ ), LC ( $p = 0.001$ ), RC ( $p = 0.001$ ), LP ( $p = 0.000$ ) and RP ( $p = 0.000$ ).

Finally, we observed a significant Presentation x ROIs interaction between 1500 and 1750 ms [ $F(5175) = 3.486$ ;  $p = 0.027$ ;  $\eta^2_p = 0.091$ ]. Results from pairwise comparisons indicated that in all these ROIs new stimuli were associated with lower amplitudes compared to old stimuli [ROIs: LA ( $p = 0.009$ ); RA ( $p = 0.009$ ); LC ( $p = 0.003$ ); RC ( $p = 0.002$ ); LP ( $p = 0.000$ ); RP ( $p = 0.001$ )]. Induced grand average activity is shown in [Fig. 5](#).

#### 4. Discussion

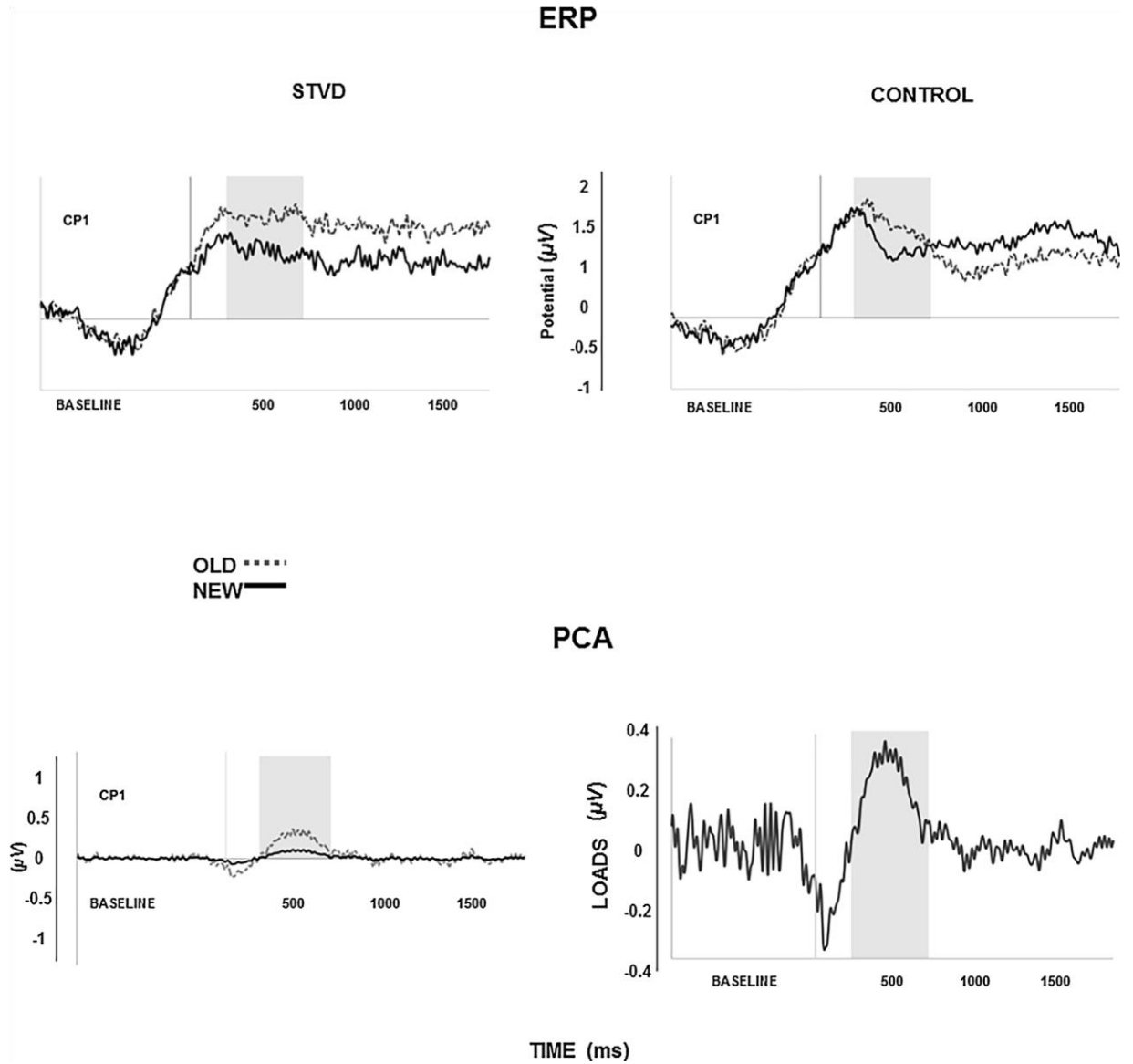


Fig. 3. Grand Averaged ERPs and PCA results showing the old/new effect in the LPC at a representative electrode (CP1). Stvd: short-term visually deprived.

The aim of this work was to investigate the effects of short-term visual deprivation on haptic recognition memory. The present results indicate that haptic recognition memory improved after short-term visual deprivation. Thus, visually deprived participants were faster than controls to recognize new familiar objects, even though a reliable old/new effect was observed in both groups. At a neural level, we observed a haptic ERP old/new effect in both groups of participants. Remarkably, an ERP old/new effect starting at



1000 ms was found only for the visually deprived participants. Additionally, neural changes were also observed in EROs. In particular, in the lower-1 alpha band we found a larger desynchronization for the processing of new compared to repeated objects in visually deprived participants between 500 and 750 ms after stimulus onset. In the following, we will discuss the implications of these results.

#### 4.1. Short-term visual deprivation influence on behavioral old/new effects

In the current study, we did not find differences in accuracy between visually deprived and control participants neither in the haptic nor in the verbal memory tasks. Nonetheless, in line with previous studies on haptic memory (Ballesteros et al., 1999; Craddock & Lawson, 2008; Sebastian et al., 2011), we observed a robust old/new effect in both groups of participants. As expected, old objects were recognized faster than novel stimuli. Interestingly, we found that visually deprived participants were faster than controls to explore the new objects, which suggests a faster access to their representation in long-term memory. We also expected a similar speeded processing for old objects in deprived participants. However, ceiling effects could partially account for the lack of differences since both groups were very fast when processing repeated stimuli.

The faster access to the conceptual representation of new stimuli in long-term memory might be attributed to an enhancement in tactile perception in the visually deprived participants. Evidence for a perceptual facilitation after 2 h of visual deprivation during the tactile discrimination of 2D shapes has previously been reported (Weisser et al., 2005). In this study, visually deprived participants were more accurate than the control group to passively discriminate the global forms of two uppercase letters (T and V) and to detect the microspatial features of a gap in a bar. Furthermore, the authors observed differences between deprived and control participants in the activation of extrastriate areas. Activation in these regions has been also related to the processing of sharp edge and discontinuities in depth (Tsao et al., 2003), as well as to tactile processing of raised dot patterns (Merabet et al., 2007). Therefore, in our study it might be speculated that increased responsiveness to the object features in the visually deprived group might be the consequence of changes in the activation of extrastriate cortices. However, this tentative explanation needs to receive further support from future research using neuroimaging techniques with a high spatial resolution such as fMRI. Additionally, some proposals argue that transitory states of visual deprivation ‘unmask’ silent connections between visual cortex and tactile and auditory inputs. Under this view, it could be possible that visual deprivation in our study may have promoted the reallocation of alerting/processing resources from the visual towards the tactile sensory modality during the haptic processing of new objects in visually deprived participants to compensate for the visual loss. Thus, it might be speculated that a better processing of new objects as a consequence of improved tactile perception, may have eventually prompted a faster access to their representations in long term-memory. As indicated in the Introduction, this would be an adaptive, compensatory mechanism that enables the exploration of the environment in situations where vision is inoperative. Studies of short-term visual deprivation in the auditory modality provide additional support to this interpretation by showing that transitory periods of visual loss lead to enhanced performance in several auditory tasks such as harmonicity perception (Landry et al., 2013), distance estimation (Reynolds, 1989) and sound localization (Lewald, 2007). Of note, this interpretation also fits well with the results we observed in the lower-1 alpha band (see 4.3.). Alternatively, our results may also suggest changes in attentional resources during the haptic processing of new objects as a consequence of visual deprivation. According to the ‘attention to memory model’ (AtoM) proposed by Cabeza (2008), episodic retrieval engages similar functional pathways to those involved in attention. In particular, this proposal suggests that a bottom-up capture of



attention occurs whenever relevant information is retrieved. In contrast, top-down activation is involved when demanding memory search is required to achieve task goals. Under these circumstances, pre and post retrieval processes are engaged to assist episodic retrieval and to make response judgements (Cabeza, 2008). In line with this proposal, the faster RTs observed in the visually deprived group may reflect an enhanced shift of attentional resources to improve the access to object representations and the subsequent comparison in memory between old and new objects. Interestingly, this interpretation would be also in line with the ERPs results observed in the slow wave (see below).

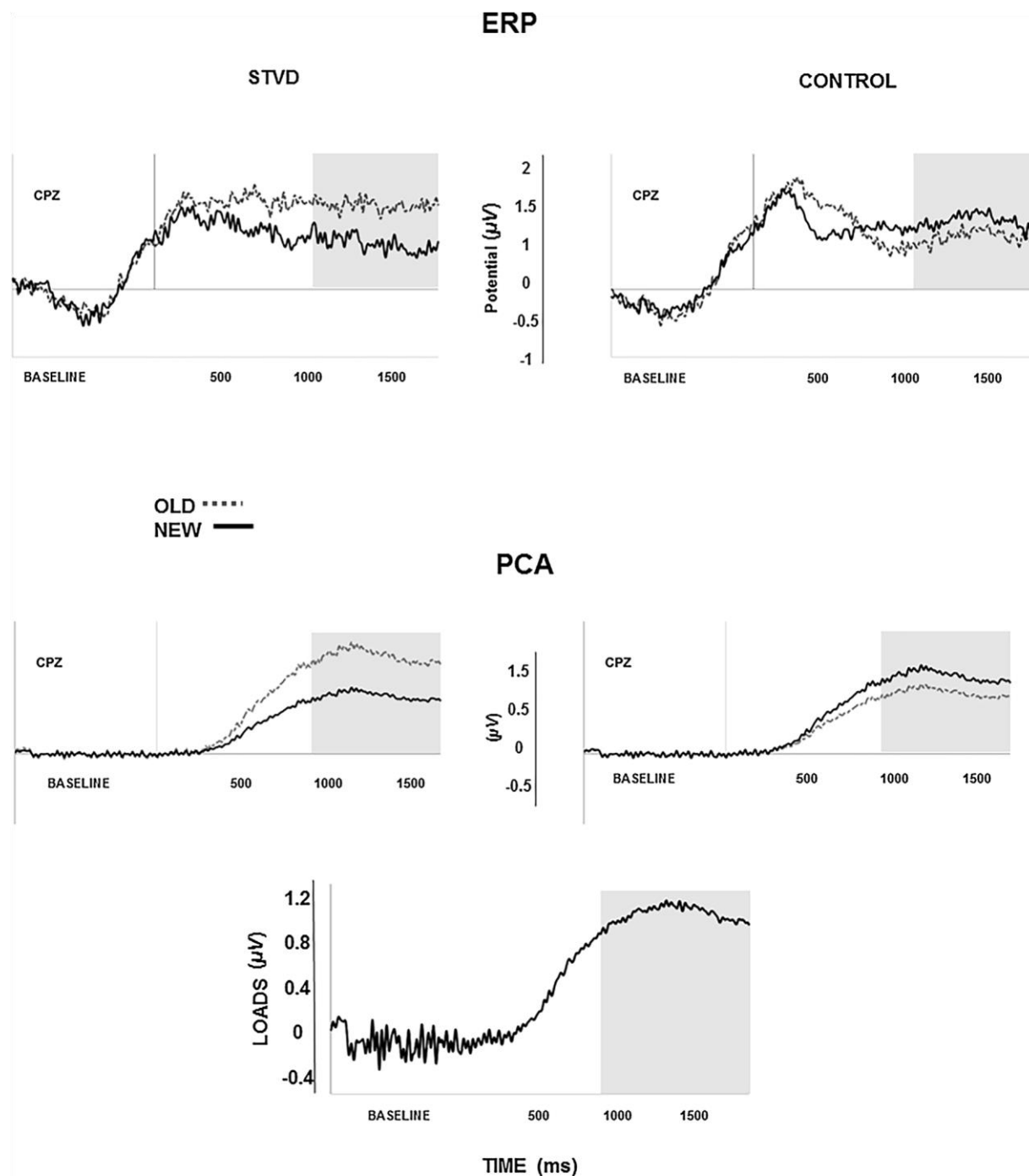


Fig. 4. Grand Averaged ERPs and PCA results showing the old/new effect in the SW at a representative electrode (CPZ). Stvd: short-term visually deprived.

**Table 3**

Significant effects of the Group factor at each frequency range.

Frequency	Time window (ms)					
	Baseline	0:250	250:500	500:750	750:1000	1000:1250
Lower-1 alpha	1.919	1.135	1.045	1.943	1.377	0.520
Lower-2 alpha	8.226**	0.367	0.030	0.460	0.051	0.061
Upper alpha	4.529*	0.013	0.891	1.624	0.840	2.225

F values (df. 1, 35) are shown. Asterisks indicate the level of significance: \* $p < 0.05$ . \*\* $p < 0.01$ .**Table 4**

Significant effects of the Presentation factor at each frequency range.

Frequency	Time window (ms)					
	Baseline	0:250	250:500	500:750	750:1000	1000:1250
Lower-1 alpha	1.134	1.219	0.046	4.962*	2.192	1.474
Lower-2 alpha	0.418	0.344	1.155	0.024	0.777	0.003
Upper alpha	0.418	0.008	1.916	0.329	0.669	0.317

F values (df. 1, 35) are shown. The asterisk indicates the level of significance: \* $p < 0.05$ .**Table 5**

Significant effects of the Presentation x Group interaction at each frequency range.

Frequency	Time window (ms)					
	Baseline	0:250	250:500	500:750	750:1000	1000:1250
Lower-1 alpha	0.182	2.137	4.532*	2.029	0.622	1.297
Lower-2 alpha	0.197	0.968	0.700	0.126	0.887	1.049
Upper alpha	0.674	0.469	0.078	0.160	0.005	1.126

F values (df. 1, 35) are shown. The asterisk indicates the level of significance: \* $p < 0.05$ .**Table 6**

Significant effects of the ROIs factor at each frequency range.

Frequency	Time window (ms)
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	Baseline	0:250	250:500	500:750	750:1000	1000:1250
Lower-1 alpha	0.748	1.431	0.181	0.227	1.843	0.228
Lower-2 alpha	0.285	2.000	0.313	0.947	1.152	0.176
Upper alpha	0.972	1.605	0.142	0.551	0.291	0.113

F values (df. 5, 175) are shown.

**Table 7**

Significant effects of the Group x ROIs interaction at each frequency range.

Frequency	Time window (ms)					
	Baseline	0:250	250:500	500:750	750:1000	1000:1250
Lower-1 alpha	0.273	1.712	1.651	1.410	0.464	0.499
Lower-2 alpha	0.477	0.499	0.269	0.672	0.701	0.281
Upper alpha	0.315	1.028	1.110	0.572	0.526	2.091

F values (df. 5, 175) are shown.

**Table 8**

Significant effects of the Presentation x ROIs interaction at each frequency range.

Frequency	Time window (ms)					
	Baseline	0:250	250:500	500:750	750:1000	1000:1250
Lower-1 alpha	0.386	1.328	1.557	0.189	0.358	0.397
Lower-2 alpha	0.687	0.391	0.284	1.508	2.588	0.975
Upper alpha	0.502	0.912	0.185	0.547	1.491	1.057

F values (df. 5, 175) are shown. The asterisk indicates the level of significance: \*p < 0.05.

**Table 9**

Significant effects of the Presentation x ROIs x Group interaction at each frequency range.

Frequency	Time window (ms)					
	Baseline	0:250	250:500	500:750	750:1000	1000:1250
Lower-1 alpha	0.254	0.254	1.276	3.286*	1.558	0.512

Lower-2 alpha	0.417	1.263	2.877*	6.159**	3.089*	1.514
Upper alpha	0.443	2.156	2.757	3.520*	1.845	0.958

F values (df. 5, 175) are shown. Asterisks indicate the level of significance: \* $p < 0.05$ . \*\* $p < 0.01$ .

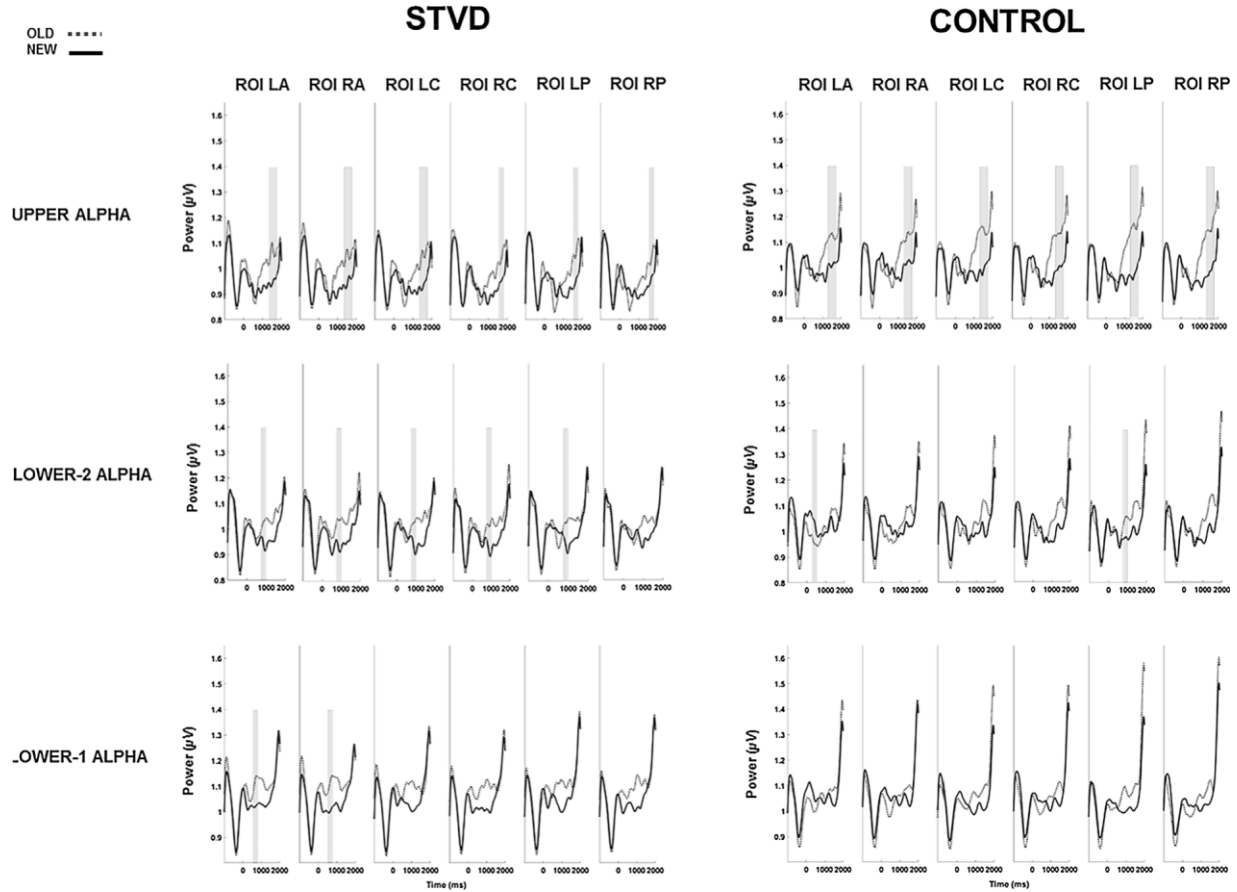


Fig. 5. Induced grand averaged activity illustrating the Group x Presentation x ROIs interaction in lower-1 alpha (500–750 ms), in lower-2 alpha (250–500 and 750–1000 ms) and in upper alpha band (1250–1500 ms) as well as the Presentation x ROIs interaction (1500–1750 ms) at ROIs: LA, RA, LC, RC, LP and RP for both control and short-term visually deprived participants. Grey rectangles show significant results. Stvd: short-term visually deprived.

#### 4.2. Short-term visual deprivation influence on ERPs old/new effect

In line with the results from a previous study on haptic recognition memory (Sebastian et al., 2011), we found that old compared to new stimuli showed larger LPC amplitudes over centro-posterior electrodes in both groups. Since this component has been related to recollection processes in the haptic modality (Sebastian et al., 2011), our data suggest that no differences between the two groups exists in the recollection of haptic memories from prior experiences with objects. Remarkably, an ERP old/new effect starting at 1000 ms after stimulus onset was specifically observed for visually deprived participants. In particular, we found larger amplitudes in this slow wave for the processing of old compared to new stimuli. Although this effect was largely found over the whole scalp its activity was maximum over centro-posterior spatial regions. A similar effect has been reported in a previous study by Roder et al. (2001).

The authors observed an old/new effect around 1000 ms for blind participants in an incidental auditory memory task with a recognition phase test. These results were interpreted as reflecting a more efficient use of retrieval strategies –e.g., post-retrieval evaluation of the stimulus and/or retrieval monitoring – in blind compared to control participants. Furthermore, [Roder et al. \(2001\)](#) proposed that these effects could be explained by a better processing of the stimulus during the encoding phase. In agreement with these findings, our data suggest the use of improved memory retrieval strategies in visually deprived participants, which possibly arose from a more efficient encoding of new stimuli due to enhanced haptic perception. This idea fits well with the speeded RTs found in our study for the processing of new stimuli in visually deprived participants. Alternatively, this effect may also depend on the additional recruitment of attentional resources during the processing of new stimuli, which would be in line with the claims made by the AtoM model as we have previously mentioned.

#### 4.3. Short-term visual deprivation influence on EROs

Results from time frequency analyses showed differences between the visually deprived and the control groups in the lower-1 alpha band in the LA and RA ROIs (500–750 ms). In particular, the deprived group showed a stronger desynchronization (i.e, lower power in this band) for the new objects compared to the old stimuli. According to [Klimesch \(1999\)](#), a greater desynchronization in this frequency band is associated with an increased level of phasic alert or arousal. Since visually deprived participants showed a stronger desynchronization for novel objects, our data seem to suggest that an increased state of arousal improved the processing of object features in the visually deprived group. Thus, in line with our behavioral results, the unmasking of latent connections in other sensory modalities following visual deprivation may account for the improved processing of the tactile features of the objects.

With regards to the group effects, we reported a stronger desynchronization at baseline in the visually deprived group compared to the controls in the lower-2 alpha and upper alpha bands, which according to [Klimesch \(1999\)](#) may be associated with increased expectations for stimuli presentation and task specific processes. Remarkably, similar effects have previously been described in haptic memory studies, which were thought to reflect modulations of attentional processes ([Sebastian & Ballesteros, 2012](#); [Sebastian et al., 2011](#)). In particular, the greater alpha reduction observed in the visually deprived group may reflect an increased recruitment of attentional resources in order to deal with task requirements. In fact, this reduction is consistent with both decreased inhibitory processing and increased cognitive processing ([Klimesch, Sauseng, & Hanslmayr, 2007](#)). Reduced activity in alpha power has been also observed in blind individuals over parieto-occipital brain regions and has been related to increased excitability in the visual cortex ([Hawellek et al., 2013](#); [Kriegseis et al., 2006](#)). Taken together these results support the view that oscillatory changes in alpha power may represent a marker of cortical reorganization ([Kriegseis et al., 2006](#)). In addition, higher power for old stimuli was observed in lower2 alpha for both groups between 750 and 1000 ms, suggesting decreased attention to repeated stimuli. Of note, the control participants also showed reduced power to old stimuli between 250 and 500 ms, which possibly suggests increased attention to repeated objects.

Finally, we observed higher power for old stimuli in the upper alpha frequency band for both groups between 1250 and 1750 ms. Similar results have been described in another haptic memory study with a repetition priming paradigm ([Sebastian & Ballesteros, 2012](#)). The authors found stronger synchronization in this band to repeated stimuli between 1250 and 1750 ms after stimulus onset, which was interpreted to

index the access to the semantic representation of the objects (Sebastian & Ballesteros, 2012). Also, modulations in the upper alpha band have been related to successful performance in declarative semantic memory tasks (Klimesch, 1999). Thus, increased upper alpha activity in our study could be associated with semantic aspects of haptic recognition memory.

#### 4.4. Limitations

A possible confound of the current study concerns the adaptation period prior to the haptic task in the visual deprivation condition, which may have improved task performance in this group. In this sense, whereas visually deprived participants started the haptic recognition memory task following a two hours period of complete light deprivation, participants in the control group were only deprived at the beginning of the task. Therefore, it cannot be totally ruled out that the poorer performance in control compared to visually deprived participants reflects not only improved haptic memory recognition in the deprived group but also a lack of adaptation to visual deprivation in the control group, which could have interfered with task performance. However, this possibility seems unlikely since participants from both groups performed a 5 min practice block prior to the haptic task. In fact, this practice allowed the participants to familiarize with the task. Remarkably, the results from the control group in the verbal tasks, as well as accuracy ratings in the haptic task seem to corroborate the efficacy of this procedure.

#### **5. Conclusions**

In conclusion, our data show that a period of two hours of visual deprivation influenced the access to object representations in memory. In particular, we observed a facilitated processing of haptic-related information in the visually deprived participants during the processing of new objects, which likely facilitated their subsequent recognition through an improved recollection of information stored in memory. This effect might be linked to the “unmasking” of latent pathways between visual cortex and tactile inputs, although an explanation in terms of attentional processes could also account for our data. In this sense, a rapid neural reorganization of the visual cortex in visually deprived participants may result in improved processing of tactile stimuli and enhanced memory performance in the haptic task. Further studies with other sensory modalities (i.e. auditory) will be of interest to assess the occurrence of short-term visual deprivation effects on recognition memory.

Declarations of interest None.

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