Neuropsychologia 48 (2010) 3360–3364

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Brief communication

Disruption of synaesthesia by posthypnotic suggestion: An ERP study

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ARTICLE INFO

Article history:
Received 4 January 2010
Received in revised form 10 May 2010
Accepted 2 July 2010
Available online 17 July 2010

Keywords:
Synaesthesia
Automaticity
Posthypnotic suggestion
Hypnosis
Cognitive control
N400

ABSTRACT

This study examined whether the behavioral and electrophysiological correlates of synaesthetic response conflict could be disrupted by posthypnotic suggestion. We recorded event-related brain potentials while a highly suggestible face-color synaesthete and matched controls viewed congruently and incongruently colored faces in a color-naming task. The synaesthete, but not the controls, displayed slower response times, and greater P1 and sustained N400 ERP components over frontal-midline electrodes for incongruent than congruent faces. The behavioral and N400 markers of response conflict, but not the P1, were abolished following a posthypnotic suggestion for the termination of the participant's synaesthesia and reinstated following the cancellation of the suggestion. These findings demonstrate that the conscious experience of synaesthesia can be temporarily abolished by cognitive control.

1. Introduction

Synaesthesia is an unusual neurological condition characterized by anomalous correspondences between and within sensory modalities. For individuals with synaesthesia, a particular sensory stimulus (an *inducer*) consistently evokes a secondary experience (a *concurrent*) of a different form and content from the stimulus, most commonly a color photism. Concurrents have repeatedly been found to elicit Stroop-like interference effects in color-naming tasks, with slower response times for incongruently colored inducers (stimulus-photism mismatches) than congruently colored inducers (stimulus-photism matches) (Ward & Mattingley, 2006). The repeated observation of these effects has generated a broad consensus that synaesthesia is automatic and resistant to cognitive control (Hochel & Milán, 2008).

In a separate context, it has been demonstrated that interference effects in selective attention tasks can be temporarily abolished using posthypnotic suggestion. A posthypnotic suggestion for the inability to read color words following a hypnotic de-induction produced a marked attenuation of Stroop interference in highly suggestible individuals, but not low suggestible controls (Raz, Fan, & Posner, 2005). This effect has been independently replicated with a flanker task (Iani, Ricci, Gherri, & Rubichi, 2006). Attenuation of Stroop interference in the former study was associated with reduced activation in extrastriate visual areas and the anterior cingulate cortex (Raz et al., 2005). Given the latter region's critical role in the monitoring of conflict (Carter & van Veen, 2007), these activation patterns indicate that the suggestion was able to dampen visual input, eliciting a concomitant reduction in response conflict.

This study examined whether posthypnotic suggestion could be used to temporarily abolish synaesthesia. A highly suggestible synaesthete (henceforth AR), for whom faces automatically and consistently evoke color photisms "in her mind's eye" (face-color associator synaesthesia; see Dixon, Smilek, & Merikle, 2004), participated in this study. AR, and a matched group of highly suggestible controls without synaesthesia, completed a color-naming task comprised of congruently and incongruently colored faces while the scalp electroencephalogram (EEG) was recorded. AR subsequently completed the task following a posthypnotic suggestion for the termination of her synaesthesia and again following the cancellation of the suggestion. In addition to behavioral responses, our analysis focused on the N400 event-related brain potential (ERP) component, a negative-going deflection found over frontal-midline electrode sites approximately 400 ms after stimulus onset. This component is sensitive to response conflict in the Stroop task, as reflected in greater negativity for incongruent than congruent trials, and has been localized to the anterior cingulate cortex (Hanslmayr et al., 2008). We predicted that incongruently colored faces would elicit slower response times and a greater N400 component than congruently colored faces for AR, but not for highly suggestible controls. We further expected that both markers of response conflict would diminish after the posthypnotic suggestion, but return following its cancellation.

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0028-3932/$ – see front matter
doi:10.1016/j.neuropsychologia.2010.07.004

Table 1
Behavioral and ERP interference effects [*Mean* and (*Standard Deviation*)] for the color-naming task of a face-color synaesthete (AR) and controls.

Variable	Controls	AR					
		Control		Posthypnotic		Post-cancellation	
		S1	S2	S1	S2	S1	S2
Behavioral							
RT (ms)	−6 (21)	373	1128	−20	38	1261	1235
EP	−.02 (.02)	−.01	.00	.00	.03	.05	.01
ERP (μV)							
P1	0.42 (0.37)		2.62		1.92		3.08
N1	0.26 (1.31)		1.83		1.47		1.91
N400 (short)	0.31 (0.88)		−2.24		0.47		−2.46
N400 (long)	0.36 (0.78)		−2.13		0.85		−2.41

Note. S = session; EP = error percentage.

2. Method

2.1. Participants

AR is a 33-year-old female face-color synaesthete who exhibits high hypnotic suggestibility. Eight highly suggestible women (M_{Age} = 26, SD = 3.13) who reported having no forms of synaesthesia acted as controls. All participants had normal or corrected-to-normal vision and were right-handed (Oldfield, 1971). Participants provided informed written consent and were compensated for their participation. This study was approved by a local ethics committee.

2.2. Materials

Hypnotic suggestibility was measured in group sessions using the *Waterloo-Stanford Group Scale of Hypnotic Susceptibility, Form C* (WSGC; Bowers, 1993) and in individual sessions with the *Revised Stanford Profile Scales of Hypnotic Susceptibility* (RSPS; Weitzenhoffer & Hilgard, 1967). AR (WSGC: 8; RSPS: 32) and the controls (WSGC: M = 8.33, SD = 0.52; RSPS: M = 37.40, SD = 8.76) did not differ on either measure, $ts < 1$.

In order to examine the reliability of AR's face-color photism pairs, participants made face-color association judgments using a database of 90 monochrome faces with neutral expressions (Lundqvist & Litton, 1998; Minear & Park, 2004; Treese, Brinkmann, & Johansson, 2003) on two occasions separated by 5 months (AR) and 1 month (controls) (Ward & Mattingley, 2006). Stimuli were 8 cm wide and 11.5 cm high. AR selected a color from a 216-color palette that most closely approximated the color photism evoked by each face, whereas controls chose the color that most closely matched their first free association. All participants were unaware they would be making the judgments in the second session. Controls were instructed in the follow-up session to try to remember the color they selected for each face in the first session. The coding procedure for assessing the reliability of participants' associations was done by two raters who were masked to group membership. Exact matches (same hexidecimal color value) for a face across the two sessions received a rating of 3; near matches (±1 in color matrix) received a rating of 2; color matches (same color group) received a rating of 1; and mismatches (different color groups) received a rating of 0 (Asher, Aitken, Farooqi, Kurmani, & Baron-Cohen, 2006).

Face-color interference effects were measured using a task in which participants identified the color of different faces. Stimuli consisted of three faces with neutral expressions that evoked color photisms for AR and which were colored in one of the three corresponding colors. Hair, necks, and ears were cropped from the images. Stimuli measured 4 cm × 6.5 cm and were centrally presented against a black background along the horizontal and vertical axes of a monitor at a distance of 75 cm, subtending a visual angle of $3^{\circ} \times 5^{\circ}$. Stimulus presentation was executed with E-Prime v. 1.2 (Psychology Software Tools, Pittsburgh, PA). Each condition consisted of 72 congruent trials (stimulus-photism color match) and 216 incongruent trials (stimulus-photism color mismatch) organized into four blocks of 72 trials. Stimuli were presented for 1200 ms or until a response was collected. Jittered inter-stimulus intervals consisting of a centrally presented white fixation cross against a black background varied between 900 and 1100 ms. Responses were made by depressing one of three keys on a manual response box with the right hand. All participants complied with an instruction to not blur their vision, as corroborated by self-report, the experimenter's observations, and the removal of muscle artifacts from the ERPs.

2.3. Procedure

Controls completed the color-naming task once while scalp EEG was recorded. AR completed the task three times in two sessions separated by 5 months with EEG only recorded in the second session. In each session, AR completed the task at baseline (control condition) and then experienced a hypnotic induction (Weitzenhoffer & Hilgard, 1967). Following suggestions for increased hypnotic depth, the experimenter administered the posthypnotic suggestion:

When you wake up you will not remember anything that happened during hypnosis and you will find that your synaesthesia has disappeared. You will find that you will no longer see colors in your mind when you look at faces. You will still be able to see colors in the world and will still be able to see faces perfectly. You will not recall having ever had synaesthesia – it will be as if you had never had synaesthesia. You will remain this way until I say "okay, that is good enough". When I say those words, your synaesthesia and your memories for what happened during hypnosis will return.

AR completed the task a second time *after* the hypnotic de-induction, under the cover of the suggestion (posthypnotic condition), and again following the administration of the cancellation cue (post-cancellation condition).

2.4. EEG recording

Participants' EEG was continuously recorded with a 128 Ag-AgCl-coated carbon fiber electrode Geodesic Sensor Net™ (EGI, Eugene, OR) and amplified with an AC-coupled, 128-channel, high-input impedance amplifier (300 MΩ, Net Amps™, Electrical Geodesics Inc., Eugene, USA). Blinks and eye movements were monitored with electrodes placed on the outer canthus and infraorbital ridge of each eye. Electrodes were referenced online to the vertex and impedances were kept below 50 kΩ. Amplified analog voltages were filtered online (high band-pass: 0.3 Hz, low band-pass: 100 Hz) and sampled at 500 Hz.

2.5. Data analysis

Behavioral interference effects (incongruent trials – congruent trials) were computed for error percentages and median response times. EEG was analyzed with Netstation (Electrical Geodesics Inc., Eugene, Oregon, USA). A 0.5–15 Hz band-pass digital filter was applied to amplified EEG voltages, which were then algebraically re-referenced to the right mastoid. ERPs were identified for epochs extending from 100 ms pre-stimulus onset to 1000 ms post-onset with data baseline-corrected relative to the 100 ms pre-stimulus interval. ERP trials that contained blinks, eye movements, or other artifacts were excluded prior to data averaging. Two control participants were excluded from the data set for having fewer than 75% acceptable trials; of the remaining participants, the numbers of correct ERP trials did not differ between controls (congruent: 54–72, M = 61, SD = 6.41; incongruent: 157–202, M = 177, SD = 17.25) and AR (congruent: 63–67; M = 65, SD = 2.08; incongruent: 180–197, M = 191, SD = 9.54), $ts < 1.25$. The mean amplitude difference between congruent and incongruent trials for electrodes 5, 6, 11, and 12 (roughly corresponding to FCz) in the post-stimulus time windows from 50 to 150 ms (P1), 150 to 250 ms (N1), 400 to 600 ms (reflecting the onset to the peak of the N400 component), and 400 to 1000 ms were used as the dependent measures. The topography of the N400 was selected on the basis of a previous study of Stroop interference effects (Hanslmayr et al., 2008). Between-group comparisons for behavioral and ERP data used modified t-tests (two-tailed) for single-case study designs (Crawford & Howell, 1998).

3. Results

3.1. Behavioral results

The codings of the two raters exhibited strong inter-rater reliability, with Kappa values ranging from .53 to .92, all $ps < .001$, and were averaged for each participant. AR's face-photism correspondence score, 0.91, was greater than that of the controls, M = 0.31, SD = 0.11, $t(5) = 5.05$, $p = .004$, thereby demonstrating the reliability of her face-color associations.

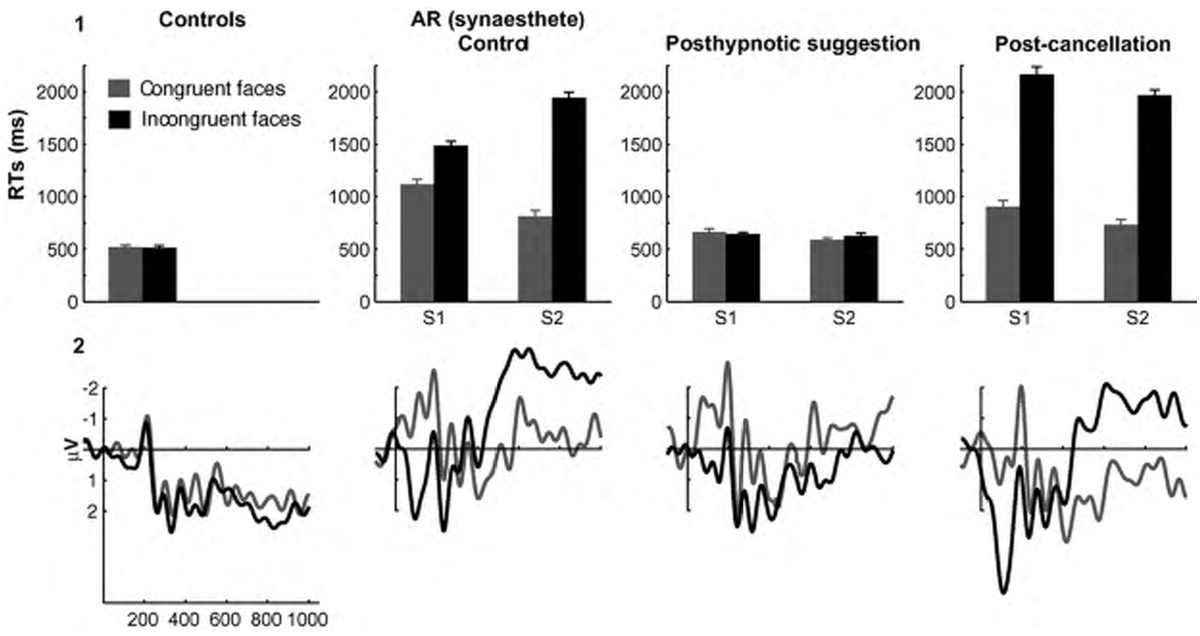

Fig. 1. (1) RTs and (2) ERPs for congruent and incongruent faces in controls and AR in control, posthypnotic, and post-cancellation conditions. S = session. Error bars represent 1 SEM.

The mean error percentage interference effect for the controls did not differ from AR's interference effect in the control, $ts(5) < 0.75$, or posthypnotic, $ts(5) < 1.95$, conditions (see Table 1). The controls' interference effect in the post-cancellation condition was smaller than AR's in session 1, $t(5) = 2.74$, $p = .041$, but not in session 2, $ts(5) < 1.25$. As can be seen in Fig. 1, AR responded to the posthypnotic suggestion for the termination of her synaesthesia and exhibited the predicted pattern of RTs in both sessions. AR's RT interference effects in the control conditions were greater than that of the controls, $ts(5) > 16$, $ps < .001$. Her interference effects subsequently decreased in the posthypnotic conditions and no longer differed from that of the controls, $ts(5) < 1.92$, but returned in the post-cancellation conditions and were again greater than that of the controls, $ts(5) > 53$, $ps < .001$.

3.2. ERP results

The behavioral interference effects observed with AR in session 2 were paralleled by three ERP components: a P1 that was more positive for incongruent faces, a N1 that was more negative for congruent faces, and a sustained anterior N400 component that was greater for incongruent faces (see Figs. 1 and 2). In an early time window (50–100 ms) over a wide region, incongruent faces were associated with greater positivity than congruent faces in AR than the control participants; this effect was present in all three conditions: control, $t(5) = 5.48$, $p = .003$, posthypnotic, $t(5) = 3.74$, $p = .013$, and post-cancellation, $t(5) = 6.63$, $p = .001$. Although congruent faces were associated with numerically greater negativity from 150 to 250 ms than incongruent faces in AR's waveforms than controls, this effect did not achieve statistical significance in any of the conditions, $ts(5) < 1.25$.

In both short (400–600 ms) and long (400–1000 ms) time windows, incongruent faces elicited greater negativity in anterior regions than congruent faces for AR in the control condition relative to controls, short: $t(5) = 2.68$, $p = .044$, long: $t(5) = 2.96$, $p = .032$. This amplitude difference decreased in the posthypnotic condition for AR and no longer differed from that of the controls, short: $t(5) = 0.17$, $p = .88$, long: $t(5) = 0.58$, $p = .59$, but returned in the post-cancellation condition and was again more negative than that of the controls, short: $t(5) = 2.91$, $p = .033$, long: $t(5) = 3.29$, $p = .022$.

4. Discussion

In a selective attention task comprised of congruently and incongruently colored faces, a highly suggestible face-color synaesthete exhibited marked interference effects at baseline, as reflected by reliably slower response times, a larger P1 component and a greater sustained, anterior N400 component for incongruent faces. This behavioral interference effect has been previously reported with a synaesthete (Milán et al., 2007), although the inducer set in that study also included non-facial visual stimuli, and points to the apparent automaticity of face-color synaesthesia. The P1 effects indicate that differences between congruent and incongruent faces are already present at early processing stages, whereas insofar as the N400 shares its topography with the N400 found for incongruent trials in the Stroop color-naming task (Hanslmayr et al., 2008), N400 magnitude differences between congruent and incongruent faces plausibly reflect increased response conflict for stimulus-photism mismatches. As predicted, AR's synaesthesia was abolished following the administration of a posthypnotic suggestion for its termination, but reinstated following the cancellation of the suggestion. The disruption and return of AR's synaesthesia were associated with the attenuation, and reinstatement, of the behavioral interference effect and N400 component, whereas the P1 effects did not differ across conditions. These findings indicate that synaesthesia can be inhibited using posthypnotic suggestion and challenge the prevailing assumption that it is resistant to cognitive control (Hochel & Milán, 2008). They also conceptually replicate the finding that posthypnotic suggestion can attenuate interference effects in selective attention tasks (Raz et al., 2005) and corroborate a host of previous studies which have found that hypnotic suggestions modulate late, explicit processing, but not early, implicit processing (Kihlstrom, 1998).

Future research would benefit from considering how disruption of synaesthesia by posthypnotic suggestion differs from its disruption using transcranial magnetic stimulation (TMS). Abolishment of grapheme-color synaesthesia using TMS occurs through the direct disruption of multisensory integration pathways in the right parietal occipital junction (Esterman, Verstynen, Ivry, & Robertson, 2006; Muggleton, Tsakanikos, Walsh, & Ward, 2007). Posthyp-

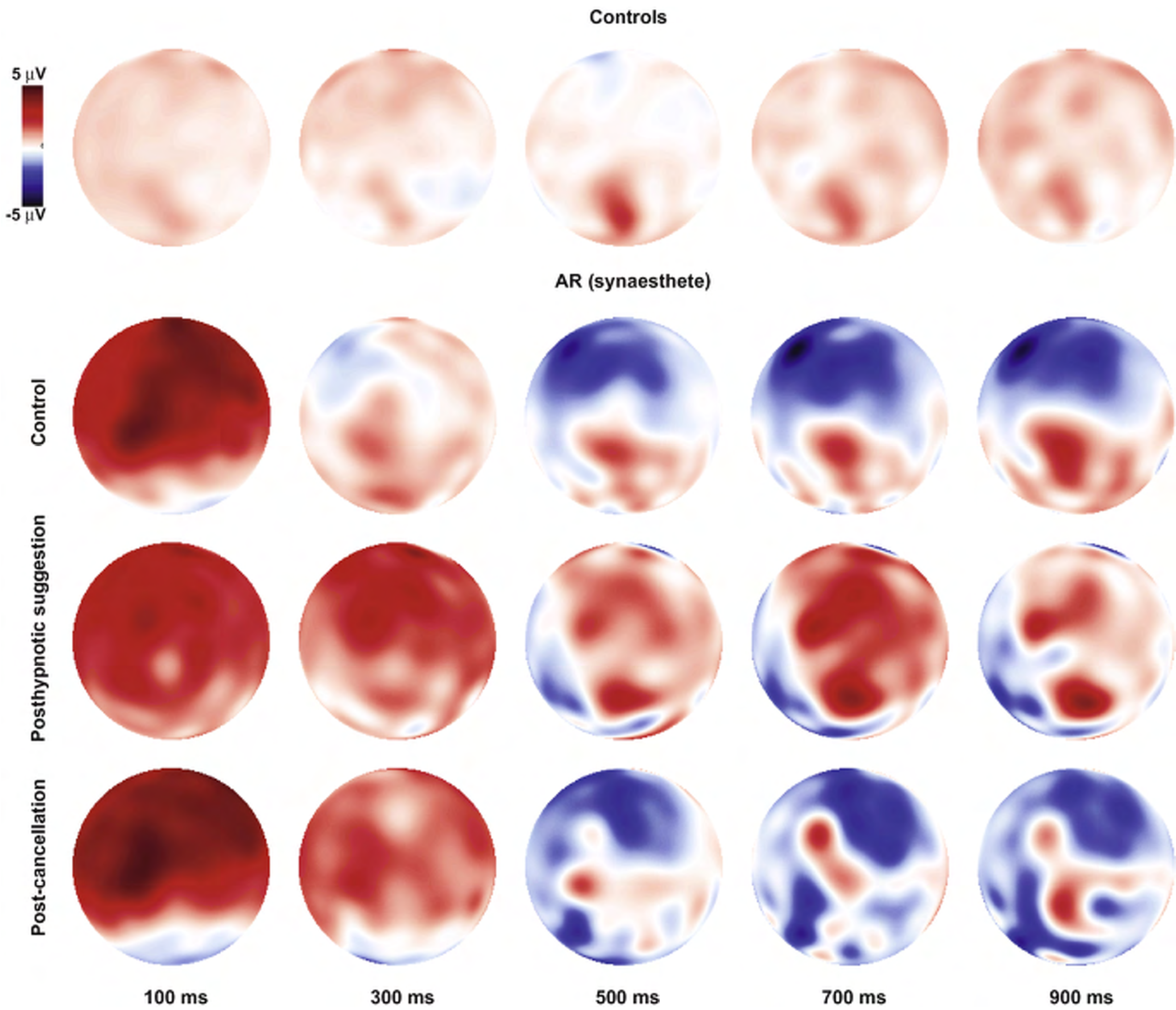

Fig. 2. Scalp topographies (incongruent faces – congruent faces) in controls and AR in control, posthypnotic, and post-cancellation conditions.

notic suggestion may indirectly prevent the conscious expression of color photisms through an early top-down process originating in the prefrontal cortex (e.g., orbitofrontal cortex; Halligan, Athwal, Oakley, & Frackowiak, 2000; Mendelsohn, Chalamish, Solomonovich, & Dudai, 2008) that disrupts multisensory integration. Alternatively, this process may directly weaken projections along feed-forward pathways, or strengthen inhibitory projections, from the fusiform face area (face processing) to the adjacent fusiform gyrus (color processing), as might be predicted by hyperconnectivity (Ramachandran & Hubbard, 2001), and disinhibition (Grossenbacher & Lovelace, 2001) theories of synaesthesia, respectively.

A limitation of the present methodology is that use of posthypnotic suggestion to modulate synaesthesia is not amenable to wide application. Insofar as the prevalence rates of high hypnotic suggestibility (10–15%; McConkey & Barnier, 2004) and synaesthesia (1–4%; Simner et al., 2006) are relatively low, the prevalence of highly suggestible synaesthetes will be approximately .1 to .6% (i.e., 1–6 per 1000 individuals), assuming the two conditions do not covary. Moreover, highly suggestible individuals are not a uniform population and not all are responsive to posthypnotic suggestions (McConkey & Barnier, 2004). In sum, posthypnotic suggestion will only effectively modulate synaesthesia in a small minority of synaesthetes. A second limitation is that the controls were younger, albeit non-significantly so, than AR. However, this difference cannot account for the disruption of synaesthesia in the posthypnotic suggestion. These limitations notwithstanding, this study demonstrates that posthypnotic suggestion can be used to temporarily abolish the conscious expression of synaesthetic photisms. When considered alongside a recent study demonstrating that grapheme-color synaesthesia can be induced in highly suggestible non-synaesthetes by posthypnotic suggestion (Cohen Kadosh, Henik, Catena, Walsh, & Fuentes, 2009), this study points to the efficacy of the instrumental use of hypnosis for evaluating assumptions and predictions that hitherto have been difficult to test (Oakley & Halligan, 2009).

Acknowledgements

This work was supported by Bial Foundation Grant 54/06. The methodological suggestions of Anne-Cécile Treese and research assistance of Tina Koch and David Marcusson-Clavertz are gratefully acknowledged.

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