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Research Article

Induced Cross-Modal Synaesthetic Experience Without Abnormal Neuronal Connections

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ABSTRACT—*Are the kinds of abnormal cross-modal interactions seen in synaesthesia or following brain damage due to hyperconnectivity between or within brain areas, or are they a result of lack of inhibition? This question is highly contested. Here we show that posthypnotic suggestion induces abnormal cross-modal experience similar to that observed in congenital grapheme-color synaesthesia. Given the short time frame of the experiment, it is unlikely that new cortical connections were established, so we conclude that synaesthesia can result from disinhibition between brain areas.*

People see with their eyes, hear with their ears, and feel with their fingers, and they may also be aware of interactions between their senses; when people watch a movie, for example, the speakers give the illusion of sound coming from the people and events on the screen. In a small population of people, however, sensations triggered by one modality elicit either another experience in the same modality or a perception experienced in a different modality. Such abnormal cross-modal interactions can occur following brain damage (Kupers et al., 2006; Pascual-Leone, Amedi, Fregni, & Merabet, 2005; Ro et al., 2007) and are also seen in some neurologically intact individuals, such as synaesthetes (Cohen Kadosh & Henik, 2007; Rich, Bradshaw, & Mattingley, 2005; Rich & Mattingley, 2002; Robertson, 2003; Sagiv & Ward, 2006; Simner et al., 2006). Grapheme-color synaesthetes, for example, experience certain achromatic graphemes (e.g., digits) in specific colors.

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A better understanding of the causes of synaesthesia and, in turn, of the causes of abnormal cross-modal interactions is fundamental for understanding cross-modal connectivity and interactions among different areas in the normal and abnormal brain (Cohen Kadosh & Henik, 2007; Sagiv & Ward, 2006). It is also important for understanding other phenomena, such as perceptual awareness, feature binding (Robertson, 2003), and automaticity (Cohen Kadosh & Henik, 2007).

Two explanations of abnormal cross-modal interactions have been provided: First, they may be due to greater-than-normal neuronal connectivity between brain areas (the *hyperconnectivity hypothesis*; Bargary & Mitchell, 2008; Maurer, 1997; Ramachandran & Hubbard, 2001; Rouw & Scholte, 2007). Second, the abnormal experience may be mediated by the same neuronal connections that exist in normal brains, and the unusual experience may be induced by disinhibition of signals within or between brain areas (the *disinhibition-unmasking hypothesis*; Cohen Kadosh & Henik, 2007; Cohen Kadosh & Walsh, 2006, 2008; Grossenbacher & Lovelace, 2001). Here we show that under posthypnotic suggestion, nonsynaesthetic participants can be induced to have synaesthetic experiences. These results provide evidence that hyperconnectivity is not a necessary precondition of synaesthesia and support the notion that a change in inhibitory processes may underlie the abnormal cross-modal experience in synaesthesia.

Previous studies of abnormal cross-modal interactions have examined either neurological patients or people whose synaesthesia has a congenital origin (Blakemore, Bristow, Bird, Frith, & Ward, 2005; Cohen Kadosh, Cohen Kadosh, & Henik, 2007; Rich et al., 2006; Ro et al., 2007; Weiss, Zilles, & Fink, 2005). These studies have resulted in a variety of mechanisms being associated with abnormal cross-modal interactions. Because premorbid data on the participants tested are not available in these studies, their conclusions are necessarily ex post facto (Cohen Kadosh, Cohen Kadosh, Schuhmann, et al., 2007; Walsh & Pascual-Leone, 2003). Here we report a study in which

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we used posthypnotic suggestion to test the possibility that changes in the way the nonsynaesthetic brain functions would be sufficient to produce the experiences reported in grapheme-color synaesthetes. Our intention was to provide a strong test of whether synaesthetic experience requires excess cortical connectivity (the hyperconnectivity hypothesis).

Using posthypnotic suggestion in neurologically normal participants, we induced abnormal cross-modal interactions (between digits and colors) that were akin to the experience reported by grapheme-color synaesthetes. The motivation behind using posthypnotic suggestion was twofold: First, induction (in an otherwise nonsynaesthete) of synaesthesia that is phenomenologically and behaviorally similar to congenital synaesthesia would suggest that abnormal cross-modal interaction can occur in the absence of excess neuronal connections. Second, it has been suggested that hypnosis affects the level of inhibition (Gruzelier, 2006), and previous studies have used posthypnotic suggestion to increase inhibitory effects via modulation of top-down processes (Raz, Fan, & Posner, 2005). However, to date, no work has used posthypnotic suggestion to decrease inhibitory influence, and such a decrease might be the mechanism behind synaesthesia (Cohen Kadosh & Henik, 2007; Cohen Kadosh & Walsh, 2006, 2008; Grossenbacher & Lovelace, 2001) and other abnormal cross-modal interactions (Cohen Kadosh & Henik, 2007; Kupers et al., 2006; Pascual-Leone et al., 2005). Note that a previous study found that hypnosis alters color perception and brain activation via modulation of V4 (e.g., hypnosis caused participants to see color as shades of gray; Kosslyn, Thompson, Costantini-Ferrando, Alpert, & Spiegel, 2000).

We hypnotized a group of nonsynaesthetes who were unfamiliar with and naive about synaesthesia, and instructed them to associate digits and colors. Subsequently, they performed a task during which this association would function as a posthypnotic suggestion. In posthypnotic suggestion, participants usually comply with a suggestion that was made during an earlier hypnotic session. In contrast with hypnotic suggestions, posthypnotic suggestions take effect during wakefulness, and commonly the participant does not remember having been told to adhere to a specific instruction (Raz & Shapiro, 2002).

METHOD

Participants

Twelve right-handed students from a first course in either psychology or pedagogy were tested: 4 in the posthypnotic-suggestion group (3 females, 1 male; ages 19–23 years, mean age = 20.5 years, $SD = 1.7$), 4 in the first control group (naive control; 3 females, 1 male; ages 20–22 years, mean age = 21 years, $SD = 0.7$), and 4 in the second control group (hypnosis control; all females; ages 20–21 years, mean age = 20.25 years, $SD = 0.5$). Participants in the posthypnotic-suggestion group and the hypnosis control group had been screened for suggestibility using the Stanford Hypnotic Susceptibility Scale (Form C; SHSS:C), with the anosmia-to-ammonia challenge excluded[1] (Weitzenhoffer & Hilgard, 1962). Individuals with the maximum possible score (11 out of 11) were selected to take part in the experiment. All participants had normal or corrected-to-normal vision and normal reading skills. Informed consent was obtained after the nature and possible consequences of the study were explained, and participants were subsequently debriefed. The study was approved by the local ethics committee.

Control Groups

In our design, each participant in the posthypnotic-suggestion group served as his or her own control (i.e., we compared performance with and without posthypnotic suggestion). However, one might suggest that the time these participants spent with the experimenter had an influence on the results, possibly because of demand characteristics (Orne, 1962). In order to preclude this as an explanation of any findings, we included two different control groups.

Participants in the naive control group were not hypnotized. Instead, the first time they met the experimenter, they remained fully awake and were given the same instructions to associate numbers and colors that were given to participants in the hypnotic-suggestion group. The hypnosis control group included highly hypnotizable participants who were hypnotized by the same experimenter and spent approximately the same amount of time with the experimenter as the posthypnotic-suggestion group. They received the same instructions as the posthypnotic-suggestion group, but in this case, the digit-color associations were introduced after the hypnosis session, once the participants were in a conscious state. Thus, this group received the instructions to associate numbers and colors while they were fully awake (the association condition, which was equivalent to the posthypnotic-suggestion condition of the posthypnotic-suggestion group; see Procedure), or to ignore this association (no-association condition, which was equivalent to the no-posthypnotic-suggestion condition in the posthypnotic suggestion group). The inclusion of these two control groups allowed us to examine whether the performance of the posthypnotic-suggestion group was due to uncontrolled factors, such as familiarization with the experimenter or level of suggestibility, or whether, as expected, the synaesthetic experience of this group resulted from the posthypnotic suggestion.

Selection for the Posthypnotic-Suggestion and Hypnosis Control Groups

Students volunteered to participate in a suggestion session, in which the experimenter evaluated their level of suggestibility. This session took place in a classroom. Only those who followed the suggestions were asked to participate in a second stage. The

[1]Following other researchers (e.g., Raz et al., 2005), we deleted this challenge because of lack of relevance for our study.

second stage took place in a dimly lit room. Participants were first given instructions to relax and then were told to enter into a deep sleep; they were also told that their right arm would rise as the sleep became deeper and deeper. Only those participants who raised their right arm were selected for the final phase, which consisted of an individual session in the lab. In the final phase, the Spanish translation of the SHSS:C was used. A previous study (González, Valle-Inclán, & Díaz, 1996) validated this translated version in a Spanish sample; results for this Spanish sample did not differ from those previously reported for North American participants (Hilgard, 1965).

We selected only highly susceptible participants for the posthypnotic-suggestion and hypnosis control groups because we thought the people with the highest susceptibility would be able to keep digit-color associations for a long period of time and because one of the crucial requirements for the study was posthypnotic amnesia. Posthypnotic amnesia was important so we could examine whether the phenomenological experience of the "virtual" synaesthetes was similar to that of congenital synaesthetes; the virtual synaesthetes did not remember that they were instructed to have digit-color association.

Before the study, participants in these two groups were hypnotized several times so they would associate the hypnotized state with a simple touch to their forehead. The criterion for passing to the experimental task was to raise one arm to vertical (as participants had been instructed to do during a previous hypnosis session) in less than 30 s after the touch.

Procedure

Each of the digits from 1 to 6 was assigned a color (1-red, 2-yellow, 3-green, 4-turquoise, 5-blue, and 6-purple). The participants in the posthypnotic-suggestion group were not told that they had received a posthypnotic suggestion that would induce changes in their perception.

Participants in the posthypnotic-suggestion group performed the experimental task in two conditions. For the posthypnotic-suggestion condition, they were previously hypnotized by one of the authors (L.J.F.) to create the digit-color associations. Under hypnosis, they were presented with the digits 1 to 6 on a black background on a computer screen. Each digit was displayed in the color with which it was associated. While the digit was displayed, the instructions for the posthypnotic suggestion were given: "Look at that color; this is the color of the digit _, and whenever you see, think, or imagine that digit, you will always perceive it in that color." For the no-posthypnotic-suggestion condition, these participants performed the same task without the posthypnotic suggestion. When the no-posthypnotic-suggestion condition followed the posthypnotic-suggestion condition, the posthypnotic suggestion was eliminated under hypnosis.

Participants in the hypnosis control group also performed the experimental task in two conditions. In the association condition, they received instructions to associate the digits with the colors (after the hypnosis episode); in the no-association condition, they were told to ignore these instructions.

Participants in the naive control group were not hypnotized. They performed the task while fully awake after receiving instructions describing the digit-color associations. These instructions were similar to those given to the posthypnotic-suggestion group.

Note that the posthypnotic-suggestion instructions were given to induce *projector* synaesthesia, the experience of seeing the color on the surface of the evoking digit (Dixon, Smilek, & Merikle, 2004; Ward, Li, Salih, & Sagiv, 2007). Note also that if participants had experienced the color in a different spatial reference frame (e.g., above the digit), that would have led to a null result in this experiment (Sagiv & Robertson, 2005).

Digit Detection Task

In addition to collecting phenomenological reports (see Results), we used a version of an objective task that has been used in previous studies (Smilek, Dixon, Cudahy, & Merikle, 2001). Participants were required to detect the presence of an achromatic digit presented on a colored background that could be congruent or incongruent with the digit's assigned color (Fig. 1). It has been shown that grapheme-color synaesthetes are more prone to errors (failure to detect the presence of the digit) in the congruent condition than in the incongruent condition because of the color triggered by the achromatic grapheme (Smilek et al., 2001).

Participants viewed a 17-in. computer screen from a distance of approximately 55 cm. The stimuli subtended a vertical visual angle of 1.8° and a horizontal visual angle of 0.8° to 1.3°. A single black digit appeared on a colored background in 50% of the trials. In the congruent condition, the background color was the same as the digit's assigned color (e.g., for the digit 1, the background was red). In the incongruent condition, the background color was the color of a digit other than the one presented (e.g., for 1, the background could be blue). The ratio of congruent to incongruent trials was 1:5 in order to keep the same number of presentations for each combination of digit and background color. The 216 experimental trials were preceded by 12 practice trials. Participants were asked to press the "T" key when a digit appeared and the "V" key in the case of a blank, colored screen (no digit). Each trial began with a white fixation point, presented for 300 ms at the center of a black screen. Five hundred ms after the offset of the fixation point, a colored background with or without a black digit appeared. This display remained in view until the participant pressed a key (or until 5,000 ms had elapsed). A new stimulus appeared 1,500 ms after the participant's response, or after the display disappeared in the case of no response. Both accuracy and reaction time (RT) were emphasized.

Participants in the naive control group performed the task once. Participants in the posthypnotic-suggestion and hypnosis control groups performed the task four times, twice without the

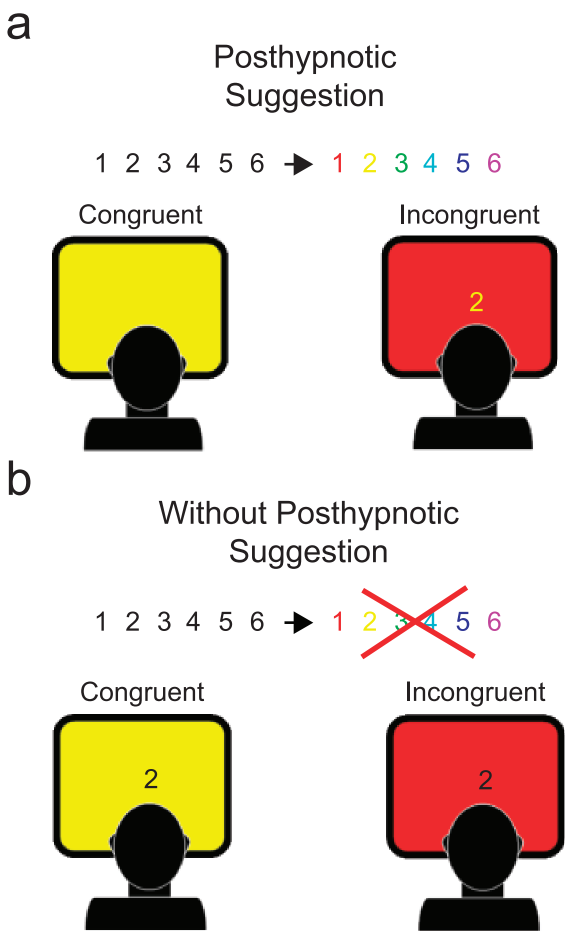

Fig. 1. The digit detection task. A single black digit appeared on a colored background in 50% of the trials, and the task was to detect whether a digit appeared on the screen. In the congruent condition, the background color was the same as the color assigned to the digit under posthypnotic suggestion; in the incongruent condition, the background color was a color assigned to a different digit under posthypnotic suggestion. The illustration in (a) indicates the subjective experience that was expected to be induced by the posthypnotic suggestion; the black digits would be perceived in the colors indicated, and therefore would not be detected in the congruent condition. When there was no posthypnotic suggestion, however, the synaesthetic experience would be absent, and the same digits would appear black (b). As a result, performance would be similar in the congruent and incongruent conditions.

instructions (or posthypnotic suggestion) associating digits with colors (A) and twice with these instructions (B). The order of the conditions was ABBA for half the participants and BAAB for the other half. Participants in these groups performed the task in two sessions separated by at least 1 week (e.g., AB followed BA a week later). The 2 participants in the ABBA design in the posthypnotic-suggestion group were left with the suggestion until the second session.

RESULTS

First we describe performance on the digit detection task. When participants in the posthypnotic-suggestion group performed the task without the posthypnotic suggestion, their performance was similar in the congruent and incongruent conditions. However, when they performed the task with the posthypnotic suggestion, each of these participants showed significant deterioration of performance in the congruent condition (i.e., when a digit's suggested association was the same color as the background), all $\chi^2(1, N = 1) > 17.38$, $p < .00003$ (see Figs. 2a–2d).

We examined whether there were any cumulative effects of suggestion by testing 2 subjects immediately after the posthypnotic suggestion and again 1 week later, still with the posthypnotic suggestion (ABBA order). The effect was found to be consistent over time. One participant made 14 errors (out of 18 possible) in the congruent condition both when examined immediately after the posthypnotic suggestion and when examined 1 week later, and the other participant made 14 errors in the congruent condition when examined immediately after the posthypnotic suggestion and 15 errors when examined after 1 week, χ^2s$(1, N = 1) < 0.33$, *p*s $> .56$. The other 2 participants (those whose posthypnotic suggestion was canceled and then recreated; i.e., BAAB order) showed no differences in performance in the congruent condition between the first and the second testing with the posthypnotic suggestion: One made 12 errors in the first session and 13 errors in the second session, and the other made 15 errors in each session, χ^2s$(1, N = 1) < 0.2$, *p*s $> .65$.

Because of the large error rate (a total of 6, 7, 8, and 11 correct trials for the 4 participants, respectively), we could not conduct a statistical analysis on the RTs. Nevertheless, we examined whether the results were due to a speed-accuracy trade-off (i.e., lower accuracy because of faster RT). We calculated the median RT and the error rate (with posthypnotic suggestion minus without posthypnotic suggestion) for the congruent condition and the incongruent condition separately. The correlation between RT and error rate was significant and positive for the congruent condition, $r = .99$, $t(2) = 9.97$, $p < .01$ (two-tailed), but was not significant for the incongruent condition, $r = -.58$, $t(2) = -1.02$, $p < .4$. Although this analysis was based on a small number of trials, it excludes the possibility of a speed-accuracy trade-off.

The naive and hypnosis control groups performed similarly to each other. Accuracy data did not show any modulation by congruence, all χ^2s$(1, N = 1) < 0.6$, all *p*s $> .43$ (see Figs. 2e and 2f), and mirrored the pattern that was observed in the posthypnotic-suggestion group when they performed the task without posthypnotic suggestion.

In addition, we used the d' psychophysical metric derived from signal detection theory to analyze results for the posthypnotic-suggestion group (see Fig. 3). The virtue of using d' is that it is criterion (i.e., response bias) independent and is therefore a strong measure of sensory processing. The d' values were significantly smaller with posthypnotic suggestion ($d' = 1.7$) than without posthypnotic suggestion ($d' = 3.6$) in the congruent condition, $t(3) = 2.96$, $p = .02$ (one-tailed). In the incongruent

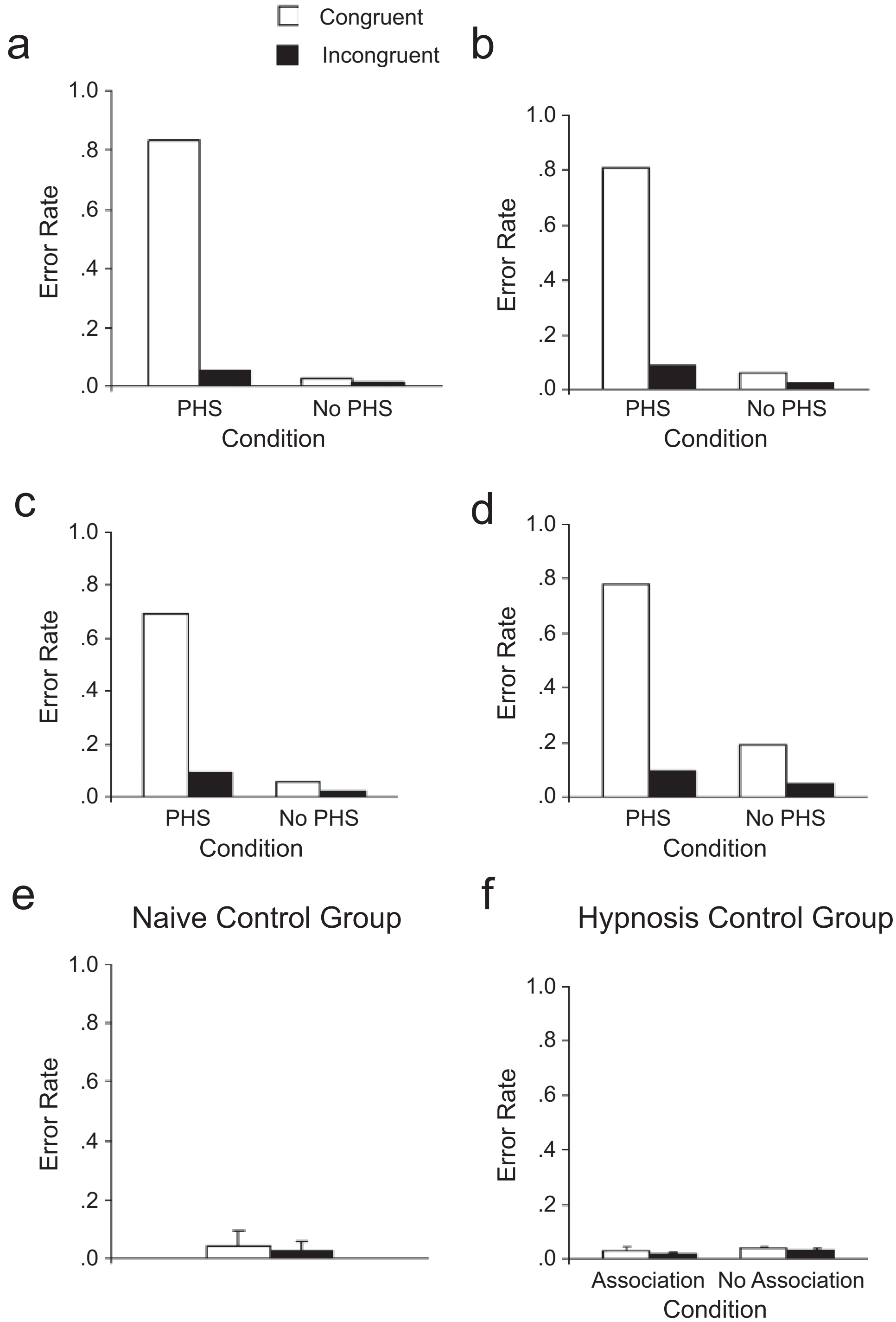

Fig. 2. Error rates of the three groups of participants in the congruent and incongruent conditions. Results are shown for each of the 4 participants in the posthypnotic-suggestion group (a–d), for the naive control group (e), and for the hypnosis control group (f). The posthypnotic-suggestion group performed the task both with and without the posthypnotic suggestion (PHS) associating digits with colors, and the hypnosis control group performed the task both with and without being given instructions to make the digit-color associations. Error bars depict 1 *SEM*.

condition, the d' values were not significantly different between performance with the posthypnotic suggestion ($d' = 4.0$) and performance without the posthypnotic suggestion ($d' = 4.1$), $p = .8$. Notably, measurement of the criterion did not differ between the posthypnotic-suggestion condition and the no-post-hypnotic-suggestion condition, $p = .53$. Therefore, the d' analysis supports the idea that posthypnotic suggestion created a new sensory cross-modal experience in these participants.

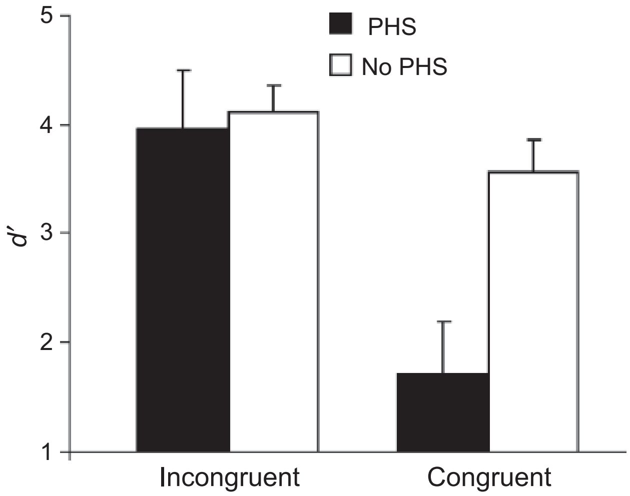

Fig. 3. Results from the signal detection analysis of the performance of the posthypnotic-suggestion group. The d' values are graphed as a function of congruence condition (congruent vs. incongruent), separately for the posthypnotic-suggestion (PHS) and the no-posthypnotic-suggestion (no PHS) conditions. Error bars depict 1 *SEM*.

At the phenomenological level, participants' reports after the posthypnotic suggestion matched those observed in congenital synaesthetes (the movie in the supporting information available on-line shows a participant describing her experience; see p. 265). The cross-modal experience was consistent and involuntary, and occurred in their everyday life. For example, one participant reported seeing the digit-color associations when looking at cars' license plates or watching television.

DISCUSSION

The current results show that posthypnotic suggestion can induce in nonsynaesthetes experiences and behavior similar to those of congenital synaesthetes. These results challenge the hyperconnectivity hypothesis because the nonsynaesthetes in our study lacked the extra structural connectivity proposed by that hypothesis.

Our results also challenge a recent study that presented evidence supporting the idea that abnormal cross-modal interactions in the case of grapheme-color synaesthesia are caused by hyperconnectivity (Rouw & Scholte, 2007). However, the structural differences reported in that study may have been due to factors secondary to, rather than causal of, the synaesthetic experience. For example, disinhibition can lead to anatomical reorganization (Cohen Kadosh & Henik, 2007; Cohen Kadosh & Walsh, 2008).

Our findings cannot be explained by the creation of abnormal neuronal connections because such new anatomical connections could not arise, become functional, and suddenly degenerate in the short time scale of this experiment (Kupers et al., 2006; Pascual-Leone et al., 2005). It has been suggested that hypnosis affects the levels of cortical inhibition, possibly via the frontal cortex (Gruzelier, 2006), and hypnosis has also been shown to modulate the level of stimulus inhibition (Raz et al., 2005). Therefore, the current results support the notion that a change in cortical inhibitory processes may underlie the abnormal cross-modal experience in grapheme-color synaesthesia (Cohen Kadosh & Henik, 2007; Cohen Kadosh & Walsh, 2006, 2008; Grossenbacher & Lovelace, 2001), and that hyperconnectivity of neuronal connections, due to incomplete pruning during development (Bargary & Mitchell, 2008; Maurer, 1997; Rouw & Scholte, 2007), is not a necessary condition for synaesthesia.

One could still argue that it is possible that the cross-modal experience induced in congenital synaesthetes, as well as nonsynaesthetes with high hypnotizability, is mediated by hyperconnectivity, or defective pruning. This possibility is unlikely for three reasons. First, such hyperconnectivity would need to be between exact anatomical areas, such as color-sensitive areas (Hadjikhani, Liu, Dale, Cavanagh, & Tootell, 1998) and grapheme-sensitive areas (Pesenti, Thioux, Seron, & De Volder, 2000), probably in the occipitotemporal cortex, in order to induce the results we observed. However, these areas seem to be unrelated to hypnotizability, which is more associated with frontal control areas (Gruzelier, 2006). Second, although previous studies found that synaesthesia is correlated with unusual brain morphology mainly in the temporal and parietal cortices (Rouw & Scholte, 2007), a recent study found that high hypnotizability is correlated with morphological changes in the right medial presupplementary motor cortex and in the right medial orbitofrontal cortex (Derbyshire, Gianaros, Whalley, & Oakley, 2008). Finally, if the current results were due to hyperconnectivity in the highly hypnotizable participants, we would have expected to find the same results in the hypnosis control group, as these participants had the same degree of hypnotizability. This was clearly not the case. Thus, it is unlikely that synaesthetes and highly hypnotizable nonsynaesthetes share the same excess neuronal connections.

The current results cannot be explained by compliance or another kind of strategy adopted by the participants. In contrast to other studies that have used posthypnotic suggestion (e.g., Raz et al., 2005), this study had a clear separation between the suggestion phase and the testing phase. Specifically, these phases did not coincide, and the participants could not have known the experimental goals (e.g., failure to detect digits only in congruent trials, phenomenological reports imitating congenital synaesthesia) from the posthypnotic suggestion. This latter point was verified in the debriefing phase after the completion of the experiment; none of the participants knew what we were expecting to find.

Smilek et al. (2001; Smilek, Dixon, & Merikle, 2005; see also Grossenbacher & Lovelace, 2001) suggested that graphemes and colors are bound together in synaesthetes via activation of different brain areas with cortical feed-forward and feedback connections, such as the occipitotemporal and parietal areas. In line with this proposal, our findings can be accounted for by functional connections mediated via changes in the degree of inhibition between these brain areas, and these changes in the degree of inhibition might be mediated via frontal regions. This idea requires further examination in studies that combine an approach similar to that of the present study with electrophysiological and neuroimaging techniques that can clarify the involvement of different brain areas (e.g., frontal and parietal lobes) in the emergence of perceptual awareness and feature binding (Esterman, Verstynen, Ivry, & Robertson, 2006; Muggleton, Tsakanikos, Walsh, & Ward, 2007; Robertson, 2003).

Given this demonstration of an induced synaesthesia, we suggest that using posthypnotic suggestion to induce other types of abnormal cross-modal interactions, such as those observed in other synaesthesias or in neurological patients, will shed light on the cognitive and neuronal mechanisms underlying cross-modal interactions and consciousness in the normal brain.

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