

Brief note

## Disruption of synaesthesia following TMS of the right posterior parietal cortex

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### Abstract

This study examines the role of four regions of the parietal lobe in grapheme-colour synaesthesia. TMS applied over a right parieto-occipital region disrupts performance on a synaesthetic priming task. TMS over the left parietal or a more anterior right parietal site did not have a reliable effect on synaesthesia even though one of the sites had been implicated in synaesthesia by previous fMRI studies. The same disruption is found for synaesthetes who experience colours in their “mind’s eye” as well as those who project colours onto the inducing grapheme. This region may be important for binding graphemes and colours to different spatial reference frames.

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### 1. Introduction

Synaesthesia is a remarkable form of anomalous cross-modal, or intra-modal, perception. One attribute of a stimulus (e.g. its sound, shape or meaning) may inevitably lead to the conscious experience of an additional attribute (often colour). Subjective reports of synaesthetic colour are corroborated by functional imaging studies showing greater activity in brain regions responsive to colour (e.g. Hubbard, Arman, Ramachandran, & Boynton, 2005; Nunn et al., 2002). However, it is likely that regions of the brain not primarily involved in visual processing are also implicated. This study uses transcranial magnetic stimulation (TMS) over regions of the parietal lobe in order to investigate the necessity of these regions for synaesthesia.

There are several reasons why regions of the parietal lobe may make an important contribution to synaesthesia. The first concerns the nature of the inducing stimulus. The most common stimuli to trigger synaesthetic experiences belong to ordinal sequences (days, months, letters, numbers; Simner et al., 2006) and this type of representation has been linked to the left angu-

lar gyrus (Hubbard, Piazza, Pinel, & Dehaene, 2005). Secondly, regions within the parietal lobes are implicated in cross-modal processing and multi-sensory integration (Ashbridge, Walsh, & Cowey, 1997; Friedman-Hill, Robertson, & Treisman, 1995). Synaesthesia is currently understood as a kind of ‘anomalous’ binding phenomenon, that is the binding of a physical stimulus (letter) to a non-physical feature (colour). One recent fMRI study, has argued that the intra-parietal sulcus may be the site that links together graphemic representation and colour processing (Weiss, Zilles, & Fink, 2005). This region was shown to be active when a grapheme evoked synaesthesia, irrespective of the actual display colour of the grapheme (i.e. whether the grapheme was shown in a colour that is congruent with the synaesthesia). Interestingly, a similar region was activated when synaesthetes listened to speech (which evoked colour) relative to tones (that did not evoke colour; Nunn et al., 2002). A third reason why parietal regions may be implicated in synaesthesia is because of their seemingly ubiquitous involvement in spatial processing and attention and, accordingly, a number of studies have shown that interference due to synaesthetic colours is reduced in attention demanding tasks that direct attention away from the synaesthetic experience (Mattingley, Payne, & Rich, 2006; Rich & Mattingley, 2003).

To date, there has only been one TMS study of synaesthesia (Esterman, Verstynen, Ivry, & Robertson, 2006). Esterman et al. found that the magnitude of synaesthetic interference (on a

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Stroop-based colour verification task) was diminished following TMS over a right parieto-occipital region but not reliably over the equivalent left region or over area V1 in two synaesthetes. They conclude that this region is important for spatial binding of colour to the inducing grapheme. In non-synaesthetes, this region is implicated in search tasks involving colour and form (Donner et al., 2002) and lesions to this region result in deficits in spatial attention (e.g. neglect; Mort et al., 2003) and colour-form binding (Friedman-Hill et al., 1995). The two synaesthetes that they tested, CP and EF, both experience their synaesthetic colours to be located in external space, on the grapheme itself. These have been termed “projector synaesthetes” to contrast them with “associator synaesthetes” who claim to experience colours internally (Dixon, Smilek, & Merikle, 2004). As Esterman et al. state: “one hypothesis to consider in future research is that synaesthetes who show greater parietal involvement may tend to be ‘projectors’, particularly when the synaesthetic percept is tightly bound spatially to the inducing grapheme” (p. 1575). However, a recent study suggests that this might not be so. Ward, Salih, Li, and Sagiv (in press) compared performance of a group of projectors and associators on a task involving detection of graphemes and colours from a briefly presented grapheme in the periphery (following Hubbard, Arman et al., 2005). They concluded that both types of synaesthesia involved spatial binding of graphemes and colours, and that it is the nature of the spatial reference frame evoked that distinguishes between the two types (i.e. a perceptual versus internal/imaginal space). Associators typically report perceiving a copy of the shape of the grapheme in their mind’s eye with the colour bound to this internal representation. As such, both varieties may represent an example of anomalous binding, but with binding to different spatial reference frames within the parietal cortex.

The aim of this study is to replicate and extend the findings of Esterman et al. In particular, our aim is to determine whether the importance of the right parieto-occipital region is limited to the particular type of synaesthesia that they studied (i.e. projectors) or is found in grapheme-colour synaesthesia more generally. Our second aim is to extend the sites stimulated to include a region of left parietal cortex that was not stimulated by Esterman et al. but has been implicated by fMRI studies of synaesthesia. A colour priming paradigm was used in which synaesthetes must indicate the actual display colour of a grapheme ignoring their synaesthetic colour (which may either be congruent or incongruent with the display colour). If the presence of TMS disrupts the presence/automaticity of synaesthesia then the degree of interference should be reduced.

## 2. Method

### 2.1. Participants

Five synaesthetes who experience colours from letters and digits took part (mean age = 29.0 years, range = 22–39 years; 4 females, 1 male). The reliability of their colours for 26 letters and 10 digits was shown to be stable over a 7.2 month interval (range = 3–12 months) achieving a consistency score of 96% (range = 86–100%). Previous research with control participants retested over 2 weeks found a consistency of 33% (S.D. = 14.2) for these stimuli (Ward & Simner, 2005). One of the synaesthetes (VE) reports her colours to be localised on the page, in external space (a so-called ‘projector’). This synaesthete has

taken part in previous studies that demonstrate the authenticity of her synaesthesia (Ward et al., in press). The other four synaesthetes report experiencing their colours on an internal screen in their “mind’s eye”. These synaesthetes are classed as associators.

### 2.2. Behavioural testing

Each participant was given eight blocks over two testing sessions. One session consisted of a block of sham TMS, a block of no TMS, TMS over a right parietal (RP) site and TMS over a left parietal (LP) site. The other session consisted of a block of sham TMS, a block of no TMS, TMS over a right parieto-occipital site (RPO) and TMS over a left parieto-occipital (LPO) site. Each block consisted of 40 trials containing 20 congruent and 20 incongruent trials randomly ordered. Two graphemes were chosen that elicited different colour experiences, and these were displayed either in their appropriate colour or with the colour associations swapped. The procedure for each trial was as follows. A fixation cross was displayed for 1500 ms. Following this the grapheme was displayed centrally in a neutral colour (black) for 200 ms before changing to the congruent or incongruent colour. The coloured stimulus remained on the screen until a response was made. This manipulation was carried out because previous studies have suggested that this may enhance the interference presumably because some minimal amount of grapheme processing is required before colour induction (Ward, Tsakanikos, & Bray, 2006). TMS was delivered for 500 ms following initial presentation of the grapheme at a rate of 10 Hz. Participants were required to make one of two button presses as quickly and accurately as possible to indicate the veridical colour of the stimulus (ignoring their synaesthesia). Button presses were used rather than voice onset because the sound of the TMS pulse may trigger the voice key.

### 2.3. TMS and MRI localisation

Prior to testing, each participant was given a T1-weighted MRI structural scan. The structural scans for each participant were normalised against a standard template using the FSL software package (FMRIB, Oxford). This produces a matrix file for each participant with the description of the normalisation transformation which was applied to the coordinates to be stimulated. This gives the locations of each site in the untransformed image. These locations were entered into the BrainSight software (Rogue Research, Montreal, Canada) to perform frameless stereotaxy. The coordinates of the LP site was  $x = -38$ ,  $y = -56$ ,  $z = 38$  and was close to the coordinates obtained in the fMRI studies of Nunn et al. (2002) and Weiss et al. (2005). The coordinates of the RPO site ( $x = 22$ ,  $y = -71$ ,  $z = 27$ ) were based on a previous study of grapheme-colour binding in visual search tasks (Donner et al., 2002) and was similar to the site chosen by Esterman et al. ( $x = 30$ ,  $y = -74$ ,  $z = 32$ ). The two remaining sites (RP and LPO) were chosen as hemispheric homologues to the sites of interest and there were no prior predictions concerning these sites. The two right hemisphere sites are shown in Fig. 1. Prior to testing the machine output was set at 60% of maximum, which was above motor threshold for all participants.

## 3. Results

Given the small group size and variability in the absolute size of the interference effects, nonparametric tests were used. For each synaesthete in each condition, the interference effect (in ms) was calculated by subtracting the response time in the congruent condition from the response time in the incongruent condition. The interference effect did not differ between the two control conditions of sham TMS and no TMS (Wilcoxon = 1.75, N.S.), and so these two control conditions were collapsed for analysis. Fig. 2 (top) shows the results of rTMS stimulation over the four parietal lobe sites relative to control TMS. Only stimulation over the RPO site produced a reliable difference between TMS and the control condition (Wilcoxon = 2.03,  $P < .05$ ). This trend was found in all of the synaesthetes tested. Fig. 2 (bottom) shows the data from individual synaesthetes from the

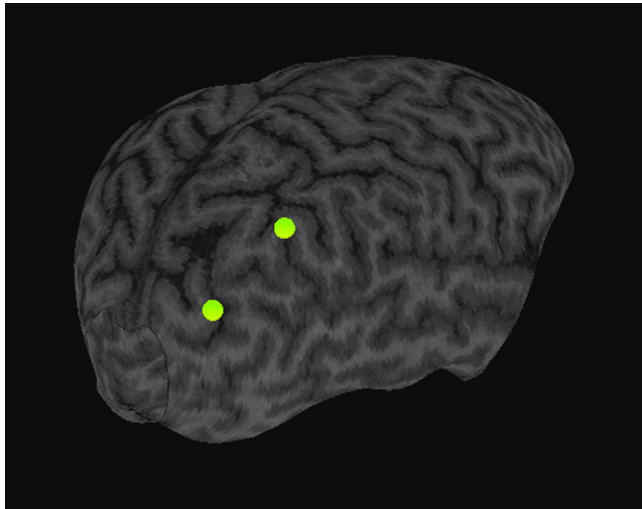


Fig. 1. The location of stimulation sites in the right parieto-occipital (RPO) region and right parietal (RP) region.

right parieto-occipital site only, together with data from the two synaesthetes (CP and EF) tested by Esterman et al. (2006). Although the TMS protocols used here and in Esterman et al. differed, they are nevertheless comparable. The same trend was noted in each and every synaesthete, irrespective of their status as a projector or associator. The reduction in interference was due entirely to reduced response times on the incongruent trials during TMS. This is consistent with TMS preventing the parietal cortex from forming a new conjunction between the grapheme and the incongruent colour. The mean response times (ms) for congruent trials in the TMS and control conditions were 415 and 413, respectively ( $N=5$ , Wilcoxon  $P=.89$ ). The mean response times (ms) for incongruent trials in the TMS and control conditions were 461 and 517, respectively ( $N=5$ , Wilcoxon  $P<.05$ ).

For the other parietal sites, the effect was very variable across synaesthetes. Although the mean was numerically similar over the RP and LPO sites, only 2/5 and 4/5 synaesthetes, respectively, showed the trend in the direction of reduced interference (Wilcoxon  $P=.23$  and  $P=.08$ , respectively). On the basis of these data, however, it seems that these regions could play a role in some specific sub categories of synaesthesia that remain to be investigated. The LP site, which was selected on the basis of fMRI data, showed the least reliable effect of all the sites tested (Wilcoxon  $P=.67$ ).

#### 4. General discussion

In this experiment, four different sites within the parietal lobes were stimulated whilst synaesthetes performed a colour verification task in which the synaesthete must respond to the actual display colour and ignore their synaesthetic colour. A reduction in interference following TMS would be indicative of disruption of the mechanism that gives rise to the interference, i.e. a disruption of synaesthesia itself. This was only reliably found at one of the parietal sites stimulated that was located at the right parieto-occipital junction. This site is close to the region

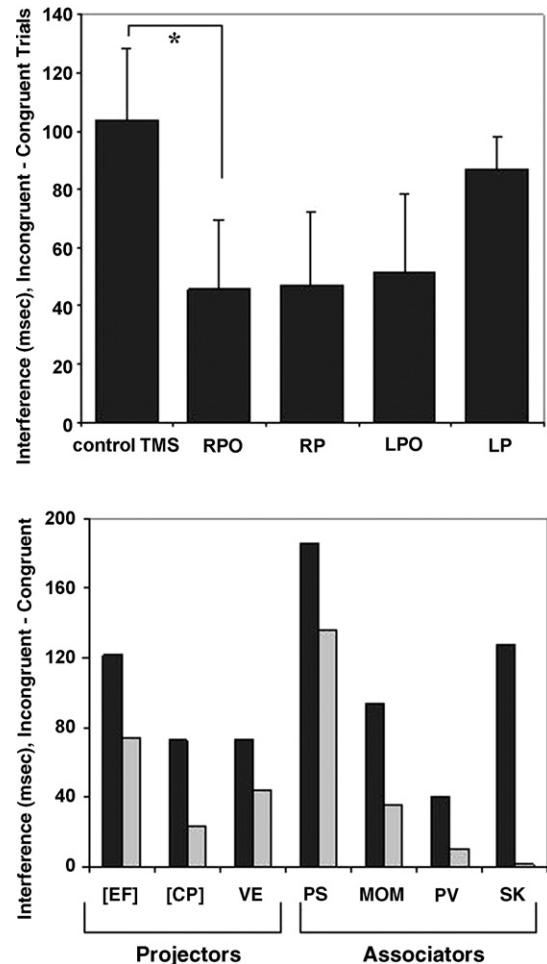


Fig. 2. Interference between real and synaesthetic colour (ms) calculated as the difference between response times for incongruent vs. congruent stimuli for a control condition relative to TMS stimulation. The top graph shows the group results over four different sites (RPO, LPO=right and left parieto-occipital; RP, LP=right and left parietal). Error bars show SEM.  $*P<.05$ . The bottom graph shows performance of individual synaesthetes following stimulation of the RPO region relative to control condition. Synaesthetes EP and CF (shown in square brackets) were reported by Esterman et al. (2006) and are shown here for comparison.

stimulated by Esterman et al. in two other cases of synaesthesia. However, our study extends the findings of Esterman et al. because four out of five of our synaesthetes report a qualitatively different kind of grapheme-colour synaesthesia. Namely, they are ‘associators’ who do not experience their synaesthetic colours as bound to an external percept of the inducing grapheme (Dixon et al., 2004; Ward et al., in press). At face value this may appear to contradict the interpretation offered by Esterman et al. that this region is implicated in the spatial binding of graphemes and colours. However, other research has suggested that attention and binding to a spatial reference frame may occur in both associators and projectors, but that the spatial reference frame evoked (i.e. near space, body-centred, object-centred, internal) differs between the sub-types of synaesthesia. Associators may still have to bind a colour to a grapheme but they do so in a different spatial reference frame to projectors. The present results are consistent with this claim.

Our results were also extended to include a region of the left parietal lobe that has been implicated in at least two fMRI studies of synaesthesia (Nunn et al., 2002; Weiss et al., 2005). However, there was no reliable reduction in interference following stimulation of this region. The new TMS results suggest that the right parieto-occipital region is necessary for the experience of synaesthesia and that the left activation, reported in fMRI studies may reflect post perceptual consequences of the synaesthetic experience. Moreover, the presence of within subject control sites suggests that our results were not due to a general interference with attentional processes since the more anterior site we stimulated has been shown to interfere with performance on attentional tasks (Wojciulik & Kanwisher, 1999).

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