NOTE

RELATIVE SUPPRESSION OF MAGICAL THINKING: A TRANSCRANIAL MAGNETIC STIMULATION STUDY

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Abstract

The tendency to perceive meaning in noise (apophenia) has been linked to "magical thinking" (MT), a distinctive form of thinking associated with a range of normal cognitive styles, anomalous perceptual experiences and frank psychosis. Important aspects of MT include the propensity to imbue meaning or causality to events that might otherwise be considered coincidental. Structures in the lateral temporal lobes have been hypothesised to be involved in both the clinical and non-clinical aspects of MT. Accordingly, in this study we used single-pulse transcranial magnetic stimulation (TMS) to stimulate either the left or right lateral temporal areas, or the vertex, of 12 healthy participants (balanced for similar levels of MT, delusional ideation and temporal lobe disturbance) while they were required to indicate if they had "detected" pictures, claimed to be present by the experimenters, in visual noise. Relative to the vertex, TMS inhibition of the left lateral temporal area produced significant reduced tendency to report meaningful information, suggesting that left lateral temporal activation may be more important in MT and therefore producing and supporting anomalous beliefs and experiences. The effect cannot simply be explained by TMS induced cognitive slowing as reaction times were not affected.

Key words: delusion, asymmetry, laterality, inhibition

Introduction

Discerning meaning in apparently random or non-intentional sources remains a common human experience, as anyone who has "seen" pictures in clouds or reported figures in ambiguous projective psychological tests can testify. The experience of perceiving meaning in apparent noise was termed "apophenia", originally to describe a critical aspect of "magical thinking" (MT) commonly seen in psychotic patients who were considered to have a "specific experience of an abnormal meaningfulness" or the "unmotivated seeing of connections" (Conrad, 1958). Operationally, MT describes a process by which meaningful connections are made between semantically-distant or unrelated percepts (Brugger et al., 1993a, 1993b; Gianotti et al., 2001; Krummenacher et al., 2002; Leonhard and Brugger, 1998) and is considered by some researchers to exist on a continuum ranging from creative and unusual thought (Weinstein and Graves, 2002), to anomalous perceptual experience and frank psychosis (Johns and van Os, 2001; Peters et al., 1999; Strauss, 1969).

One of the first studies to have demonstrated the induction of apophenia in a non-clinical group of participants was conducted by Barber and Calverly (1964). Using simple suggestion, they produced an experience of "hearing" the Bing Crosby song "White Christmas" in 54% of people played nothing but white noise. The use of stronger suggestion techniques increased this rate to 73% for a hypnosis condition and 80% for a condition using "task motivating instructions", compared with a rate of 40% in the control group.

A later study by Mintz and Alpert (1972) also found that 40% of non-clinical participants reported hearing "White Christmas" when played nothing but white noise; but that hallucinating patients were much more likely to "hear" the song than non-hallucinating patients. This study (and a subsequent replication by Young et al., 1987) suggested that the tendency to perceive a non-existent meaningful song from white noise is not necessarily a perception peculiar to pathological disorders, although the propensity is expected to be more consistent or stronger in people diagnosed with a psychotic illness. More recently, Merckelbach and van de Ven (2001) sought to find some of the psychological correlates of this tendency in a non-clinical population and found an association between "detecting" the non-existent song, and measures of both fantasy- and hallucination-proneness.

Other studies have suggested that there may be general tendency to perceive "patterns in noise" all of which may account for different forms of MT (Brugger et al., 1993a; Brugger and Graves, 1997; Pizzagalli et al., 2001; Gianotti et al., 2001) and that such tendencies may be explained in terms of a right hemisphere processing bias. This link with hemisphere processing has subsequently been confirmed in a number of studies using methods that included electroencephalography (EEG; Pizzagalli et al., 2000), lateralised word presentation (Brugger et al., 1993a; Kravetz et al., 1998; Leonhard and Brugger, 1998; Pizzagalli et al., 2001), lateralised visual noise presentation (Brugger et al., 1993b), olfactory discrimination (Mohr et al., 2001) and implicit line bisection measures (Taylor et al., 2002).

Pizzagalli et al. (2000) argue that the right hemisphere favours “coarse” rather than “focused” semantic processing and that a bias for right hemisphere processing may facilitate the emergence of loose and uncommon associations in both healthy participants and patients. This conclusion however, could be seen to be at odds with some of the clinical literature which has suggested a tendency for left hemisphere hyperactivity in clinically-diagnosable psychotic disorders such as schizophrenia (see review in Gur and Chin, 1999).

Although interesting, hemispheric accounts lack precision as to the neural systems involved in magical thinking, apophenia and associated anomalous experience. Suggestions as to relevant brain areas have been provided by studies that have linked the temporal lobes with paranormal beliefs and anomalous perceptual experiences. Work by Persinger and colleagues (Makarec and Persinger, 1985; Persinger and Makarec, 1987; Persinger and Fisher, 1990; Skirda and Persinger, 1993) has shown that anomalous beliefs and experiences can be reliably linked to signs of temporal-lobe disturbance in both clinical and non-clinical populations, and that anomalous experiences (including visual images, smells, emotions and the experience of a ‘sensed presence’) can be induced in some people by either applying weak complex magnetic fields (from outside the skull) over the right temporo-parietal area, or to the same area bilaterally (Persinger and Healey, 2002; although see Granqvist et al., 2005).

One relevant technique yet to be applied to the study of this phenomenon is single-pulse transcranial magnetic stimulation (TMS). TMS has a number of advantages for investigating putative neural networks, not least of which is a good spatial and temporal resolution, and the ability to safely and selectively disrupt or inhibit areas of the cortex of healthy individuals whilst they are undertaking a controlled task (Mills, 1999; Walsh and Pascual-Leone, 2003). This latter aspect allows experimental studies to move beyond the correlative designs of much of the previous work to look at the effects of neural intervention on a particular cognitive process.

In experimental studies, the tendency to detect non-existent meaningful information in visual noise patterns has been previously linked to MT and anomalous experience (Brugger et al., 1993b) and measures of psychoticism and hallucination-proneness (Jakes and Hemsley, 1986). To further understand the hypothesised role of the lateral temporal areas in MT and the psychosis-continuum, this study recruited healthy participants within the normal range for measures of MT, delusional ideation and unusual experiences and attempted to use TMS to try and affect perceptions of meaningful information in visual noise patterns.

METHOD

Participants

The study involved 12 healthy participants (6 male, 6 female; mean age = 24.08, SD = 4.08). All participants were right handed. Laterality quotient for 11 of the participants was measured by the Edinburgh Handedness Inventory (Oldfield, 1971), giving a mean of + 8.44 (range 5.0-10.0, SD = 1.82), where -10 is completely left handed and + 10 is completely right handed. Participants were unaware of the exact hypothesis being investigated and were recruited on the basis that the study was investigating “brain areas involved in perceiving and understanding ambiguous pictures”. The study was fully reviewed and approved by the appropriate local research ethics committee.

Stimulation Protocol

All participants were screened using the TMS Adult Safety Screen (Keel et al., 2001) and were subsequently interviewed by one of the medically-trained researchers (VR) to exclude anyone with a history of neurological or mental illness, current use of central nervous system medication, or any other factors contraindicated for TMS.

After screening, participants’ were measured using the 10-20 system (American Electroencephalographic Society, 1991) and areas T7 (left temporal), T8 (right temporal), Cz (vertex) and C3 (left motor cortex) were marked on the scalp.

A Magstim Super Rapid system (Magstim Company Ltd, Whitland, Wales) with a 70 mm figure-of-eight coil was used for TMS stimulation. The motor threshold for each participant was determined by finding the lowest stimulation strength needed to elicit visible movements of the digits of the right hand in 3 out of 6 pulses when areas around the left motor cortex were stimulated. Subsequent experimental stimulation was conducted at 110% of each participant’s motor threshold, with the coil positioned flat against the skull and the handle pointing towards the posterior of the skull. During the experimental phase of the study, the coil was aligned with the appropriate 10-20 location and locked in place by use of a specifically-designed coil stand (Magstim) to ensure a consistent site of stimulation. Walsh and Pascual-Leone (2003) estimate that the type of figure-of-eight coil used in this study stimulates an area of 4 cm × 3 cm on the cortical surface. Figure 1 shows coil positioning for the temporal lobe stimulation conditions.

Fig. 1 – *Approximate coil placement for left and right lateral temporal lobe stimulation.*

Procedure

Following the methodology of Brugger et al. (1993b), participants were told that they were about to be shown a series of dot patterns that would be briefly presented centrally on-screen, and that "about half" had pictures hidden within, that might range from simple forms to more complex images. Crucially, it was stressed that participants were not to try and guess which dot patterns had pictures hidden in them, but were only to respond if they detected one of the "hidden images". Actually however, all of the patterns were randomly generated and none contained "hidden images". Participants were asked to respond as quickly and accurately as possible by pressing one of two buttons with the right hand.

Trials were presented in three blocks of 40, each consisting of 20 trials of two types (single-pulse TMS stimulation given either 100 msec or 200 msec before visual noise presentation) randomly ordered throughout the block. Stimulation was presented before stimulus onset to avoid potentially confounding factors such as non-specific reaction time facilitation (Terao et al., 1998) and post-pulse hesitation by participants (Walsh and Pascual-Leone, 2003, p. 84). Two latencies were used, both to increase the chances of finding an effect and to elucidate any differences in online processing. Each of these latencies would allow the depolarising effect of TMS (approximately 500 msec to return to baseline tissue current; Walsh and Cowey, 2000) to encompass stimulus onset, and post-stimulus latencies found effective in previous non-motor TMS studies that found inhibitory effects (see Table I). Each block involved stimulation to one site only; either the left temporal, right temporal or vertex area. Blocks were rotated in a Latin-squares arrangement between participants to control for order effects.

For each trial a central fixation point was presented for 500 msec, followed by the presentation of the random dot pattern 500 msec afterwards. Single-pulse TMS stimulation was given either 100 msec or 200 msec before random dot pattern presentation. The random dot patterns were presented for 140 msec and consisted of 800 × 600 pixel (onscreen dimensions 238 mm × 178 mm) black and white dots, presented on a white background in the centre of the screen (with a total screen area of 1024 × 768 pixels). The subsequent trial was presented 500 msec after each participant response.

Participants were then asked to complete a number of scales designed to assess anomalous experiences and beliefs, namely the 21-item Peters et al. Delusions Inventory (PDI-21; Peters and Garety, 1996), a measure of delusional ideation, the Magical Ideation Scale (MIS; Eckblad and Chapman, 1983) and Makarec and Persinger's Temporal Lobe Signs Inventory (TLSI; Makarec and Persinger, 1985, 1990), a measure of anomalous experience related to temporal lobe disturbance. Owing to time constraints, one participant did not complete these scales, and so data for only 11 participants are reported here.

RESULTS

Statistical analysis was carried out using non-parametric tests, as they do not require assumptions about normal distribution of the data that would be difficult to justify in light of TMS intervention being used in all conditions (notably however, there were no substantial differences in outcome when analyses were completed using parametric

TABLE I
Effective pulse latencies in non-motor TMS studies

References	Site	Task	Effective latency
Amassian et al. (1989)	Occipital	Letter recognition	60-140 msec
Hotson et al. (1994)	Temporo-parieto-occipital junction		100-150 msec
Düzel et al. (1996)	Temporal	Serial order recall	0 and 200 msec
Ashbridge et al. (1997)	Parietal visual cortex	Conjunction search	100 and 160 msec
Kamitani and Shimojo (1999)	Occipital	Visual observation	60-180 msec
Pourtois and de Gelder (2002)	Left posterior parietal cortex	Audio visual pairing	200 msec

TABLE II
Mean median reaction times and "detect" responses by site of TMS stimulation

Location site	Mean of median RTs (SD)	Mean "detect" responses (SD)
Left	1190.21 msec (662.93)	2.42 (4.12)
Right	1212.75 msec (708.2)	4.92 (8.6)
Vertex	1202.42 msec (747.17)	5.92 (8.4)

equivalents). Effect size (ES) for each comparison was calculated according to Cohen (1988).

When median reaction times were compared using a Wilcoxon signed rank test, there were no significant differences between median reaction times on the 100 msec and 200 msec conditions for any of the stimulation sites (left -100 msec *vs.* 200 msec: Z = – 1.833, ES = .53, p = .60; vertex – 100 msec *vs.* 200 msec: Z = – 1.647, ES = .48, p = .099; right -100 msec *vs.* 200 msec: Z = – .628, ES = .18, p = .530). Therefore, these trials were collapsed for the purposes of further analyses (see Table II). A Friedman test did not reveal any effect of location site on median reaction time (χ^2 = .167, df = 2, ES = .12, p = .920). Similarly, pair-wise comparisons of individual location sites using Wilcoxon signed rank tests revealed no further differences (left *vs.* right: Z = – .157, ES = .05, p = .875; vertex *vs.* right: Z = – .196, ES = .06, p = .844; vertex *vs.* left: Z = – .157, ES = .05, p = .875) suggesting TMS did not induce any general cognitive slowing or response inhibition during the task.

However, when the number of "detect" responses were compared using a Friedman test, a significant effect of location site was found (χ^2 = 8.176, df = 2, ES = .83, p < .05). Post-hoc tests were conducted using two-tailed Wilcoxon sign rank tests to compare individual stimulation sites. In a direct comparison, there was no significant difference between "detect" responses after right and left temporal areas (Z = – 1.843, ES = .53, p = .065). However, a differential effect was found in detection whereby there was no significant difference in responding when right stimulation was compared to vertex stimulation (Z = – 1.279, ES = .37, p = .201), but a significant reduction in "detect" responses when left stimulation was compared to the vertex (Z = – 2.433, ES = .70, p < .05).

The standard deviations for group "detect" responses were notably high. This was caused by one participant responding with 14, 29 and 30 "detect" responses for the left, right and vertex stimulation conditions respectively. On questioning, the participant claimed to be responding as requested during the task (indicating 'detection' of meaningful pictures rather than 'guesses'). As this participant was unremarkable in psychometric scale scores, it cannot be discounted that the participant misunderstood the instructions (although interestingly, the pattern of responses still suggest that left stimulation reduced positive responding). When this participant's data are removed from the analyses the mean "detect" responses by site of stimulation are as follows: left (1.36; SD = 2.01), right (2.74; SD = 4.24), vertex (3.73; SD = 3.80). The pattern of significance remained unaffected however. A subsequent Friedman test on the revised data set remained significant (χ^2 = 6.467, df = 2, ES = .77, p < .05). The direct left-right comparison was non-significant (Z = – 1.549, ES = .47, p = .121), although there was still a differential effect whereby the right-vertex comparison was not significant (Z = – 1.166, ES = .35, p = .244); and there was still a significant "detection" reducing effect for left stimulation when compared to the vertex (Z = – 2.246, ES = .68, p < .05).

The mean number of items endorsed on the PDI-21 was 4.18 (range 0-8, SD = 2.99), mean MIS score was 5.08 (range 0-12, SD = 3.96) and mean TLSI score was 7.0 (range 1-15; SD = 4.36), suggesting the group was well within the normal range for these measures. There were no significant correlations between any of the psychometric scale scores and either the number of site-specific or total number of "detect" responses, suggesting pre-existing levels of anomalous or paranormal beliefs or experiences did not significantly affect the number of "detect" responses.

Barnett and Corballis (2002) have reported that consistent right-handers show lower levels of magical ideation than those with mixed-handedness, leading to a potential confound. As we wished to establish that participants were effectively homogeneous for levels of MT, a two-tailed Mann-Whitney U test was used to compare scores on the PDI-21, MIS and TLSI, between consistent right-handers (those who scored 9 or 10 on the EHI; n = 5) and inconsistent right-handers (those who scored 8 or below on the EHI; n = 6). No significant differences were found between these groups on any of the psychometric scale scores (PDI-21 consistent *vs.* non-consistent: Z = – 1.588, ES = .48, p = .112; MIS consistent *vs.* non-consistent: Z = – .188, ES = .06, p = .851; TLS consistent *vs.* non-consistent: Z = – .092, ES = .03, p = .927), suggesting that the findings were not likely to have been significantly influenced by this effect.

Discussion

The findings reported here indicate that single pulse TMS can significantly reduce the tendency to "detect" non-existent meaningful images in visual noise by inhibiting localised areas of the left lateral temporal cortex. The tendency to perceive meaning in noise (apophenia) constitutes a distinctive component of MT, a process thought by some to be important in the purported psychosis continuum. In particular the results are consistent with the idea that the temporal lobes may be important in supporting this process. The finding that reaction times were not significantly affected while "detection" rates were, suggests that the effect was not due to any general effects of cognitive slowing or response inhibition.

Methodologically, the observed effect is interesting in itself, as the current literature considers single-pulse TMS as generally having an effect on reaction time but not other response measures such as accuracy (Walsh and Pascual-Leone, 2003). Although this study did not use a task that could be scored in terms of accuracy, the pattern of results suggests that single-pulse TMS can influence behaviour without significant cognitive slowing.

The exact mechanisms of TMS are still poorly understood and it is not impossible that the stimulation used in this study was producing a facilitatory rather than inhibitory effect in the targeted areas. There are several reasons to think this is unlikely in this case however. Previous studies that have found facilitatory effects using single-pulse TMS (Ellison et al., 2003; Topper et al., 1998) have typically reported facilitation in terms of decreases in reaction time, which were not observed in our study. Furthermore, in the case of one report (Topper et al., 1998), such facilitatory effects were only present with low intensity stimulation and disappeared at levels comparable to those used here.

In terms of the specific hypothesis being tested, it is notable that the differential effect of stimulation was only found relative to the vertex, rather than from the more direct comparison between left and right temporal stimulation alone. This is perhaps due to the fact that stimulation of a region in one cortical hemisphere may cause activation in the homologous area of the opposite hemisphere, albeit more weakly and after the time taken for the signal to travel across the brain (Ilmoniemi et al., 1997). This later and lesser response may still be significant however, perhaps making it difficult to distinguish from the effect of the original site of stimulation with this paradigm, meaning only a comparison to vertex stimulation would make a differential effect apparent. It might also suggest that both lateral temporal areas may be involved in MT, although one may be preferentially involved. Nevertheless, the direct left-right comparison was only marginally non-significant, and the possibility remains that this effect could become significant with a larger sample size.

An examination of the effect sizes reported in this study also suggests that this phenomenon may become more distinct with additional investigation. Cohen (1988) approximately defines small effects as .2, medium as .5 and large as .8, with some of the non-significant comparisons displaying small to medium effect sizes. As the small sample size used in this study does not provide adequate power to confidently accept the null hypothesis in these cases, it may be that such comparisons will become significant when further participants are tested. With this in mind, this study should be considered as an initial investigation in this area.

Nevertheless, the significant results that typically show large or near large effect sizes, suggest that global hemisphere accounts (e.g., that right hemisphere processing bias leads to increased MT) need to be revised. In our study, inhibiting the left lateral temporal cortex led to a reduction in the perception of meaningful information in visual noise. If it was simply the case that whole hemisphere activation was the major influence on this process, inhibiting the left temporal area should reduce the overall level of left hemisphere activation, bias processing so the right hemisphere was preferentially involved, and increase the chances of participants "detecting" meaningful information. As this was not the case (in fact, almost the reverse was found), an alternative explanation needs to be developed to take into account neural networks on the sub-hemisphere scale.

Relevant clinical studies have typically found specific reductions in left lateral temporal lobe grey matter volume in the schizophrenia spectrum disorders (Dickey et al., 1999; McDonald et al., 2004; Pearlson et al., 1997), whereas functional neuroimaging studies have revealed increased regional cerebral blood flow in the left temporal areas, particularly the superior temporal gyrus, in patients with delusions and other "reality distortion" symptoms (see Blackwood et al., 2001 for a review).

It is not entirely clear how these structural and functional findings relate however, and it may be that increased blood flow may be due to areas with reduced grey matter having to do additional "work" to maintain an adequate level of functioning. The association between these areas and "reality distortion" experiences has typically been found with correlational studies however, and it may be the case that up- or down-stream cognitive effects, or any number of other physiological factors associated with pathology could result in the findings of such studies. As mentioned earlier, one advantage of TMS studies is that they are not purely correlational. Any effects found in such studies suggest that the targeted cortical areas are necessary for the process under investigation. In this case, the findings provide convergent evidence to accompany the imaging studies discussed by Blackwood et al. (2001), which further link the lateral temporal areas to MT processes and by implication, the clinically encountered "reality distortion" experiences.

Nevertheless, the relative specificity of TMS stimulation for these temporal areas suggests that a simple correlation between relative global hemispheric activation and MT is unlikely to account for all cases where MT might occur. As it currently stands, the literature seems to suggest that sub-clinical measures of MT are more likely to show this simple correlation, compared with formally diagnosable disorders. This might further suggest that there are multiple neuropsychological factors underling the psychosis-continuum rather than a single modulatory factor, as has also been suggested by a recent study of the schizotypy spectrum and prepulse inhibition (Abel et al., 2004).

This study only measured quantitative variables however, and there was no indication of exactly what the participants thought they saw when they indicated that they detected a "hidden image". An extension of this research might include measures of the qualitative aspects of falsely detected images (as has been done in the TMS visual-phosphene literature; Stewart et al., 1999), which might answer the question as to whether inhibiting the left lateral temporal areas simply shifts response bias, or causes the perception of more complex or unusual images, or perhaps, false images of a certain type.

Certainly, temporal areas are known to be involved in semantic memory and object recognition, and activity or partial activation in these areas might induce a number of experiences of meaningfulness, of which TMS (or any other technique) may produce only a certain type. This suggests that there may be a commonality between processes which allow percepts to be understood as meaningful, and those which are thought to be up-regulated or damaged on the higher ends of the psychosis continuum.

This potential overlap and the neural basis of the "experience of meaningfulness" may be a useful focus for future work in this area. One application of TMS that is currently being researched is its use as a treatment for various psychiatric disorders, with current paradigms focusing on longer-term suppression of cortical areas thought to be involved in producing unwanted symptoms and experiences (Fitzgerald et al., 2002). If the results in this study bear out, it may be possible to reduce levels of MT by targeting the areas identified in this study. However, considering the poorly-defined boundaries of delusion and insight, and the potential links between MT, creativity and anomalous belief, this is an area which should be approached with caution and certainly not without serious consideration as to ethical issues involved.

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