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Assessing the impact of beta stimulation on finger tapping variability: a tACS study.

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April 2017

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ABSTRACT

Neural oscillations are characterised by the frequency at which they befall, and recently there has been a growing of interest in the beta band (13-30Hz). Exaggerated beta oscillations are observed in Parkinson's disease patients, and are hypothesised to be directly linked to the motor symptoms of the disorder. Patients with Parkinson's disease appear to have a specific impairment in movements that are internally generated (IGM). A causal relationship between enhanced beta and motor deficiencies (particularly on IGM) has yet to be established. This study looked at the effect of enhanced beta – administered via transcranial alternating current stimulation (tACS) – on the ability of healthy subjects to accurately tap along to a beat. Furthermore, whether this enhanced beta would have a specific impact upon tapping accuracy without the addition of an external stimulus (auditory beat). Results revealed no significant main effects of either beta stimulation or tapping with vs without a beat on tapping accuracy. There was also no significant interaction. These findings indicate the beta oscillations are not causative of motor impairment, in particular for IGM. This extends to Parkinson's disease suggesting that pathological beta is not causative for the motor symptoms and do not have a specific impact on IGM.

KEY WORDS:	BETA BAND OSCILLATIONS	PARKINSON'S DISEASE	MOTOR SYMPTOMS	TRANSCRANIAL ALTERNATING CURRENT STIMULATION (TACS)	INTERNALLY GENERATED MOVEMENTS (IGM)
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Introduction

Neural activity is dominated by synchronised oscillations, which appear as rhythmical fluctuations in both electroencephalographs (EEG) and local field potential (LFP) recordings. Oscillations in neuronal populations are generally characterised by the frequency at which they befall, and recently there has been a growing of interest in those occurring in the beta band (13-30Hz) (Jenkinson and Brown, 2011). Beta band oscillations are prominent in the human motor system (Pogosyan et al, 2009), being recorded in regions such as the somatomotor cortex, the cerebellar system and basal ganglia (Jenkinson and Brown, 2011). The basal ganglia plays a major role in the regulation of human movement (Brown, 2003), and oscillatory activity in the beta frequency band has been identified to be ubiquitous throughout the cortico-basal ganglia (CBG) circuits. These oscillations – amongst others – become more prominent in Parkinson's disease (Hammond et al, 2007).

Parkinson's disease (PD) is a progressive, age-related neurodegenerative disorder characterised by: a slowness of movement, muscle rigidity, postural instability, and a tremor of the limbs at rest (Schroll and Hamker, 2016). Movements can be 'internally generated' (IGM; movements that are self-initiated) or 'externally generated' (EGM; movements that are externally triggered). Patients with PD appear to have a specific difficulty in producing IGMs, which is evident in their paucity of voluntary movements (bradykinesia) and a delay/failure to initiate a planned movement (akinesia). In contrast, performance is improved when external stimuli are provided (Wu et al, 2011). The mechanisms underlying the difficulty in performing self-initiated movements in PD however remain unclear (Wu et al, 2011).

A hallmark of PD pathology is the death of dopaminergic neurons in the substantia nigra pars compacta (SNc) and their striatal projections (Rivlin-Etzion et al, 2006) (see Figure 1, A). Nevertheless, the relationship between dopamine depletion within the basal ganglia, and the source of enhanced beta band oscillations remains elusive (Pavlidis et al, 2015; Beck et al, 2016). There have been several theories proposed in which suggest the origin of these pathological beta band oscillations lie within the CBG circuits. One such theory describes the globus pallidus externa (GPe) – subthalamic nucleus (STN) subnetwork (see Holgado et al, 2012).

The striatum however, has been largely ignored as a possible source of excessive beta band oscillations (McCarthy et al, 2011). Dopaminergic neurons modulate the activity of the basal ganglia, essentially through their innervation of the striatum. The striatum acts as a 'gate-way', filtering out undesirable impulses (such as unwanted motor actions) and maintains a smooth information flow into the CBG circuit (see Figure 2, B). A striatum depleted from dopamine may disrupt and pass unwanted signals therefore leading to unwanted motor behaviours (Dani and Zhou, 2004) (see Figure 1, B). This disrupted information flow following dopamine depletion is hypothesised therefore to be the source of pathological beta activity. This is evident as prominent beta band oscillations in the LFP recordings of the STN and globus pallidus internus (GPi; Moran et al, 2012; Guradi and Alegre, 2016) (see Figure 1, C).

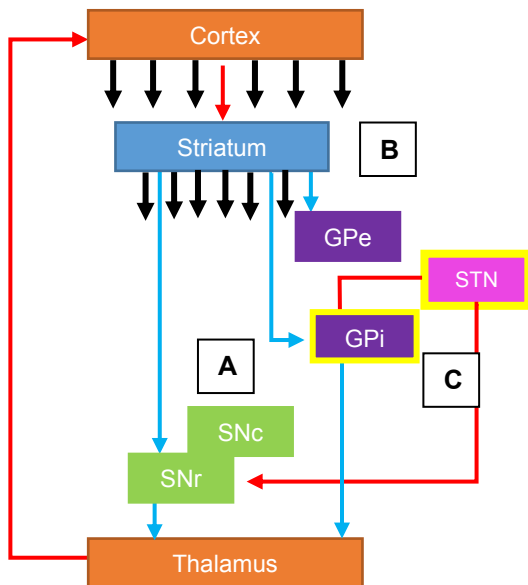


Figure 1. Very basic representation of a disrupted cortico-basal ganglia circuit in Parkinson's disease.

Excitatory pathways are shown in **red**; inhibitory pathways in **blue**.

Pathological beta is shown as a **yellow outline**.

Black arrows represent the flow of information.

(Abbreviations: SNc: substantia nigra pars compacta; SNr: substantia nigra pars reticulata; STN: subthalamic nucleus; GPi: globus pallidus internus; GPe: globus pallidus externus)

A = Death of dopaminergic neurons in the SNc lead to a dopamine deprived striatum.

B= A depleted striatum disrupts and cannot filter incoming information.

C= pathological beta occurs in all areas of the CBG circuit but is more pronounced in the STN and GPi.

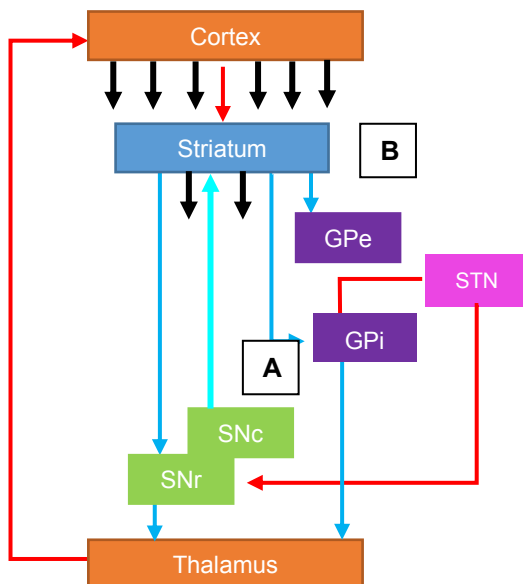


Figure 2. Very basic representation of the cortico-basal ganglia circuit.

Excitatory pathways are shown in **red**; inhibitory pathway in **blue**.

Black arrows represent the flow of information.

Turquoise arrow represents flow of dopamine.

(Abbreviations: SNc: substantia nigra pars compacta; SNr: substantia nigra pars reticulata; STN: subthalamic nucleus; GPi: globus pallidus internus; GPe: globus pallidus externus)

A = Dopamine is transmitted from the SNc to the striatum.

B= A normally functioning striatum filters out unwanted responses.

(Note not all connections are shown)

The relationship between dopamine depletion within the basal ganglia and an increase in pathological beta band oscillations is unclear. While some experimental studies have identified an upsurge in beta band oscillations following the application of a dopamine antagonist (Costa et al, 2006), others have found no such effect (Mallet et al, 2008). In contrary to predictions, Mallet and colleagues (2008) found that amplification of beta band oscillations in the CBG circuit in PD is likely the consequence of long-term dopamine depletion as opposed to an acute absence of dopamine receptor stimulation. Thus, it remains unclear if pathological beta band oscillations are directly linked to a lack of dopamine, or if they might simply be an epiphenomenon developing late in a state of chronic depletion (Beck et al, 2016).

There is a substantial amount of evidence indicating that pathologically enhanced beta band oscillations in the basal ganglia play a paramount role in the pathophysiology of PD (Beck et al, 2016). As a consequence, it has been hypothesised that enhanced beta band oscillations in the CBG circuit are directly linked to the motor symptoms associated with PD (Kuhn et al, 2004; Pogosyan et al, 2010; Little et al, 2012). A key constituent underlying this hypothesis is based on the fact that effective symptomatic treatments with dopaminergic drugs such as Levodopa (L-DOPA) reduce pathological synchrony, in tandem with improvements in akinesia and rigidity (Weinberger et al, 2006; Ray et al, 2008). In addition, high frequency deep brain stimulation (DBS) of the STN causes the suppression of beta band oscillations alongside a reduction in bradykinesia (Kuhn et al, 2008). Furthermore, DBS of the STN at beta frequencies worsens the motor symptoms of PD (Eusebio et al, 2008; Chen et al, 2011), and beta stimulation of the motor cortex in healthy individuals slows motor responses (Pogosyan et al, 2009). The correlation between improvement in motor performance and suppression of beta activity extends support for the hypothesis that pathological beta band oscillations contribute to the pathophysiology of PD.

Despite these, and many other findings advocating an importance of excessive beta band oscillations in the pathophysiology of PD, the hypothesis has been put to question by several studies. Priori and colleagues (2004) discovered that with the administration of Orphenadrine (an alternate dopaminergic medication) – as opposed to L-DOPA – improvements are observed in rigidity and tremor, however, an increase (rather than a decrease) in beta band oscillations is observed within the STN. Furthermore, Foffani and colleagues (2006) failed to show suppression of beta band LFPs following clinical improvements in the symptoms of PD after high frequency DBS. In addition, it has been found that high frequency DBS only successfully suppresses beta band LFPs in the STN of patients who have a higher beta activity at baseline (Giannicola et al, 2010). These conclusions suggest that beta band oscillations alone may not reflect the PD clinical state, and other mechanisms may also be involved in the pathophysiology of PD.

As demonstrated above, although PD clinical symptoms are presumed to be correlated with enhanced beta band oscillations, numerous attempts have failed to discover a clear relationship between the two. A correlation does not imply causation and whether enhanced beta band oscillations are causally linked to the motor symptoms of PD (mainly bradykinesia and rigidity), or the relationship is epiphenomenal, is yet to be established (Little et al, 2012).

Hypotheses

Bradykinesia (motor symptom of PD) is hypothesised to be associated with pathological beta band oscillations. However, it is not clear if the association is causative, or whether this association exists within healthy individuals. Therefore, the first hypothesis was as follows:

H1: does beta administered via transcranial alternating current stimulation (tACS) reduce the ability to accurately tap along to an auditory beat.

Furthermore, given that beta is prevalent in PD and is purported to be linked with the motor symptoms, particularly bradykinesia – which is a paucity of voluntary (IGM) movements- it is likely that excessive beta activity results in deficits of IGMs as opposed to EGMs. Therefore, the second hypothesis was as follows:

H2: does beta have a specific impact on internally generated movements versus externally generated movements.

Methodology

Design

To enable the investigation of the two hypotheses, a controlled 2X2 within-subjects factorial design was implemented. Consequently, the two independent variables and their two subsequent levels were as such:

IV 1: Stimulation of the brain via a transcranial alternating current stimulation device (tACS)

(1a) at the frequency of 20Hz (beta) versus,

(1b) a 'sham' stimulation

IV 2: A finger-tapping task

(2a) with the addition of an external aid (auditory beat) versus,

(2b) unaided (without auditory beat)

The dependent variable for this experiment was the variability in tapping accuracy

Participants

Eight participants were successfully recruited by means of opportunity sampling. Gender and age restrictions were not implemented, however, it is important to note that all participants were a minimum of eighteen years of age to enable fully informed consent. Acting in line with the Safety Transcranial Brain Stimulation Guidelines, the following exclusion criteria for participating in this study were presented: current, or prior, cardiovascular issues of any sort; diagnosis of epilepsy, or a family history of epilepsy. Furthermore, for liability reasons those who operated heavy machinery or a heavy goods vehicle (HGV) for a living were not permitted to take part.

Ethical Considerations

The researcher adhered to the ethical guidelines of the British Psychological Society (BPS), and approval for the present investigation was authorised by Manchester Metropolitan University (MMU) (APPX 1). While the investigation was entirely non-invasive, as with any brain stimulation device there were potential risks. The overall

level of risk was considered low, and there were no known risks of seizure. In the (rare) case of seizure however, appropriate staff would have been notified and the emergency services called. Upon arrival, participants were instructed to complete a screening questionnaire (APPX 6) to once more ensure they did not possess any of the exclusion criteria, followed by an informed consent form (APPX 4). After the completion of the study, participants were also required to complete a short side-effects form (APPX 7) to further ensure the safety of the participant. They were additionally given a de-brief sheet (APPX 5) and an opportunity to create a unique code for potential withdrawal if they should wish. All data gathered was stored in compliance with the Data Protection Act (1998).

Materials

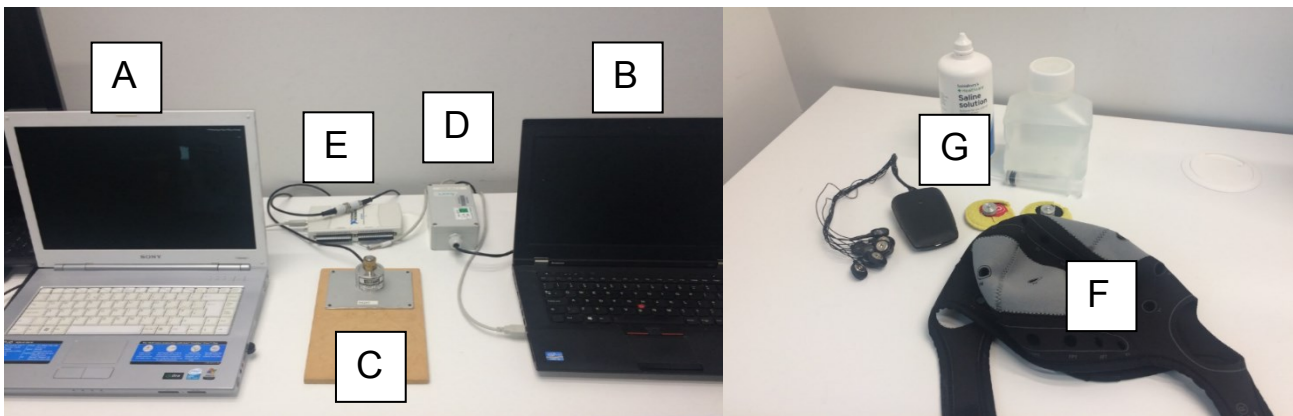


Figure 2. Visual representation of apparatus set up

A = Computer with STARSTIM software used to administer beta stimulation and sham stimulation.

B = Computer with MATLAB software

C = Novatech 40kg Load Cell.

D = Amplifier.

E = Analogue to data converter.

F = TACS cap.

G = Electrodes, electrode sponges and saline solution.

Transcranial alternating current stimulation (tACS)

TACS exerts its influence by directly interfering with cortical rhythms in a safe non-invasive manner. Through the external application of beta (20Hz) oscillating electrical currents, this investigation used tACS to influence cortical beta activity by increasing its prevalence in the motor cortex of healthy subjects.

STARSTIM transcranial stimulation (tCS) - a wireless multichannel transcranial current stimulator – was the software used to administer the stimulation (see Figure 3, A). As there were two conditions in the present study, tACS was used to administer both a beta stimulation (20Hz) and a ‘sham’ stimulation. The addition of the sham stimulation was to control for potential demand characteristics that may have occurred.

The tACS EEG like electrodes were fitted into sponges (see Figure 2, G) and required to be relatively saturated in saline solution. This was to ensure that the electrical current could pass easily to the scalp of the participants. Electrode one was connected to the C3 region of the tACS cap (see Figure 2, F), and electrode two was connected to the P8 region. C3 and P8 positioning were desirable as an electrode placed at C3 stimulated a motor region, whereas an electrode placed at P8 did not. This combination was ideal as the consequential model resulted in a stimulation of the motor cortex.

Before the present experiment went ahead, an impedance check was required to be carried out. The impedance check is an additional safety feature whereby a small amount of current is passed to the scalp. The level of safety was indicated by a 'traffic light system' i.e. green = good, red/orange = bad. Once the impedance check displayed green, stimulation could begin.

Stimulation of both beta and sham was administered twice in 4 conditions, and lasted for 5 minutes and 20 seconds each. Participants were not made aware of when they would receive the beta stimulation, or when they would receive the sham stimulation. The allocation of which stimulation to what condition was randomly assigned by the researcher to each participants, such as the following:

Beta, beta, sham, sham
 Sham, beta, sham, beta
 Sham, sham, beta, beta and so on and so forth.

Load cell

A Novatech 40kg load cell (see Figure 3, C) was the apparatus used to acquire the data from the finger tapping. A load cell is a transducer that is used to create an electrical signal whose magnitude is proportional to the force.

The load cell was connected to an amplifier (see Figure 3, D) to enhance the incoming signal, which was furthermore connected to an analogue to data converter (see Figure 3, E). This enabled the finger tapping data acquired from the load cell, to be fed through the converter in order to digitise the data. This process allowed the incoming data to be read by the connected computer in MATLAB (see Figure 3, B).

MATLAB

An in house script written in MATLAB R2014a by the researchers was used to record the data from the load cell. The script furthermore produced the auditory beats at both 500 or 650ms for the participants to tap along to, and ran for a total of 5 minutes. An additional script was written by the researchers in order to acquire the mean interval tapping and variance in tapping accuracy for each participant.

Procedure

Upon arrival, participants completed a short screening questionnaire (APPX 6) to further ensure they had none of the exclusion characteristics before partaking. An information sheet (APPX 3) was then handed to them explaining the procedure and upon acknowledgement of understanding, participants were asked to complete the essential informed consent form (APPX 4).

Participants were then instructed to assume a comfortable position on the chair provided whilst the researcher fitted the tACS cap onto the participants head, ensuring it was correctly positioned. Following that, the participants were asked if the electrode sponges inside the tACS cap felt “cold” and “damp” and when confirmed, the two electrodes were attached and an impedance check was carried out.

Once the impedance check confirmed safe stimulation, the researcher verbally explained and physically demonstrated to the participant the actions required for the experiment. By using their index finger on their dominant hand, the participants were instructed to imitate a series of auditory beeps by tapping on the load cell in unison with them, continuing the same beat when the beeping stopped. A single beep then indicated the end of that series auditory beeps. After a short time gap of two-seconds, another series of beeps were heard, but at an alternate speed (faster or slower) and the participant repeated the previous actions. This continued for a total of five minutes, and then the session was completed. Between each session, participants were given a 2 minute break to reduce the possibility of fatigue and/or boredom.

The duration of the experiment consisted of four sessions equalling a total of twenty minutes, two of which included beta stimulation (twenty hertz) and the other two a ‘sham’ stimulation. The allocation of the two different types of stimulation to which two sessions was randomly assigned for each participant. Participants were not made aware of when they would receive the beta stimulation or the sham stimulation. Following completion of the study, participants were required to complete a short side-effects form (APPX 7) and debrief sheet (APPX 5).

Data analysis

The present study was analysed in SPSS24 by means of two 2 by 2 repeated measures ANOVAs. The use of a factorial ANOVA was favourable as it revealed the main effects: impact of stimulation condition on tapping accuracy (beta vs sham) and the impact of the tapping condition (with auditory beats) on tapping accuracy. Furthermore, it enabled the ability to see if there was an interaction effect between the stimulation conditions (beta vs sham) and tapping condition (with or without an auditory beat).

Results

Table 1. Demographics and performance characteristics of participants

	<i>M</i>	<i>SD</i>
Age (years)	28.25	13.18
Mean tapping interval (ms)	567.48	13.77
Mean tapping variance (ms)	129.28	7.00
Sex	Male = 2	Female = 6

A total of 8 participants were successfully recruited for the current study. As presented in Table 1, the mean age of the participants was 28.25, and they were predominantly female. As anticipated, the participants had no problem maintaining a good level of accuracy, indicated by the mean tapping interval in each participant being close to 575 ms (which is the mean of the interval of the auditory beat that participants were aiming to emulate).

Two 2 by 2 repeated measures ANOVAs were conducted to establish whether there was a main effect of stimulation (beta vs sham) and/or tapping condition (tapping with vs without auditory beat). Additionally, the interaction between stimulation and tapping was assessed.

Mean tapping interval

The first ANOVA revealed that there was no significant main effect of stimulation on mean tapping interval: $F(1,7) = 0.001$, $p = 0.97$; additionally, there was no main effect of tapping condition (with vs without an auditory beat) on mean tapping accuracy: $F(1,7) = 0.15$, $p = 0.71$. There was also no significant interaction between stimulation and tapping conditions: $F(1,7) = 0.39$, $p = 0.55$. Figure 4 illustrates these results.

Figure 4. A bar chart displaying the means and 95% confidence intervals of the mean tapping interval in all four conditions.

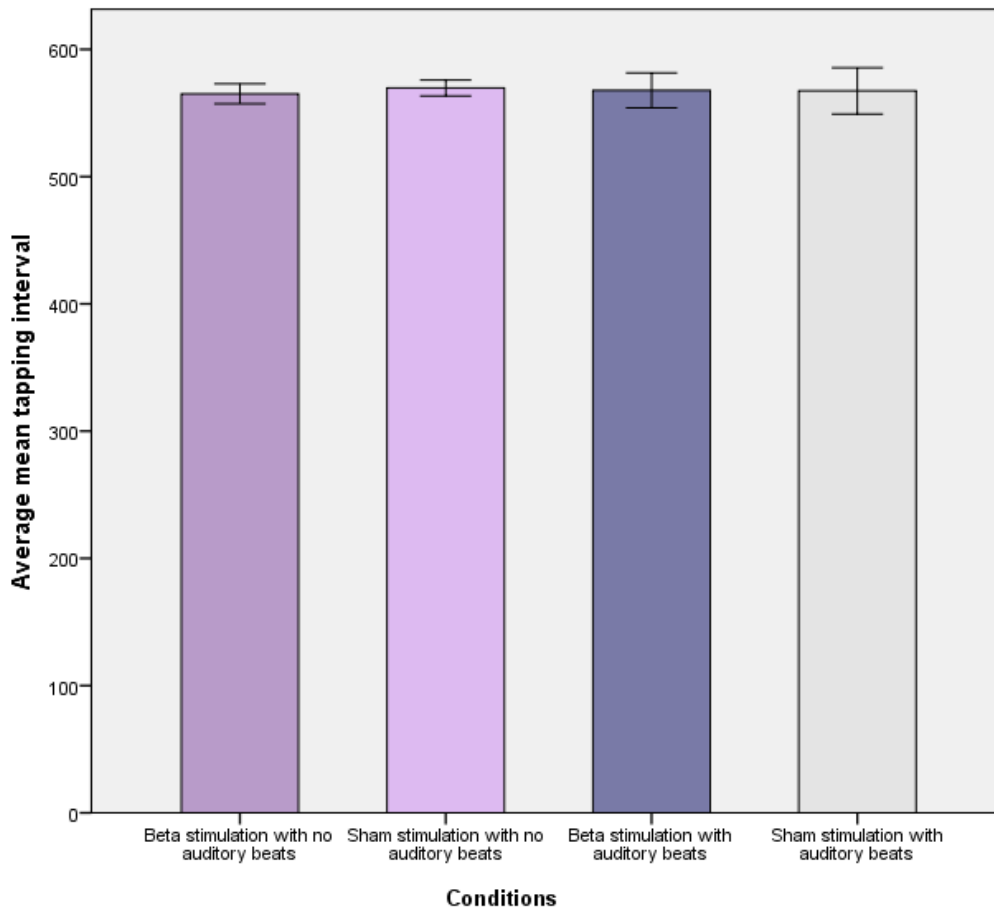


Figure 4. Bars represent the average of the mean tapping interval across participants. Error bars are the 95% confidence intervals of the mean. NB the closer the mean tapping interval is to 575, the more accurate the tapping performance.

Variance in tapping accuracy

The second repeated-measures ANOVA revealed that there was also no main effect of stimulation on the variance of tapping accuracy: $F(1,7)= 2.80, p=0.14$; nor was there a main effect of tapping condition (with vs without auditory beat) on the variance of tapping accuracy: $F(1,7)=0.27, p=0.62$. There was also no significant interaction between stimulation and tapping conditions: $F(1,7)= 0.40, p=0.55$. Figure 5 illustrates these results.

Figure 5. A bar chart displaying the means and 95% confidence intervals of the variance in tapping accuracy in all four conditions.

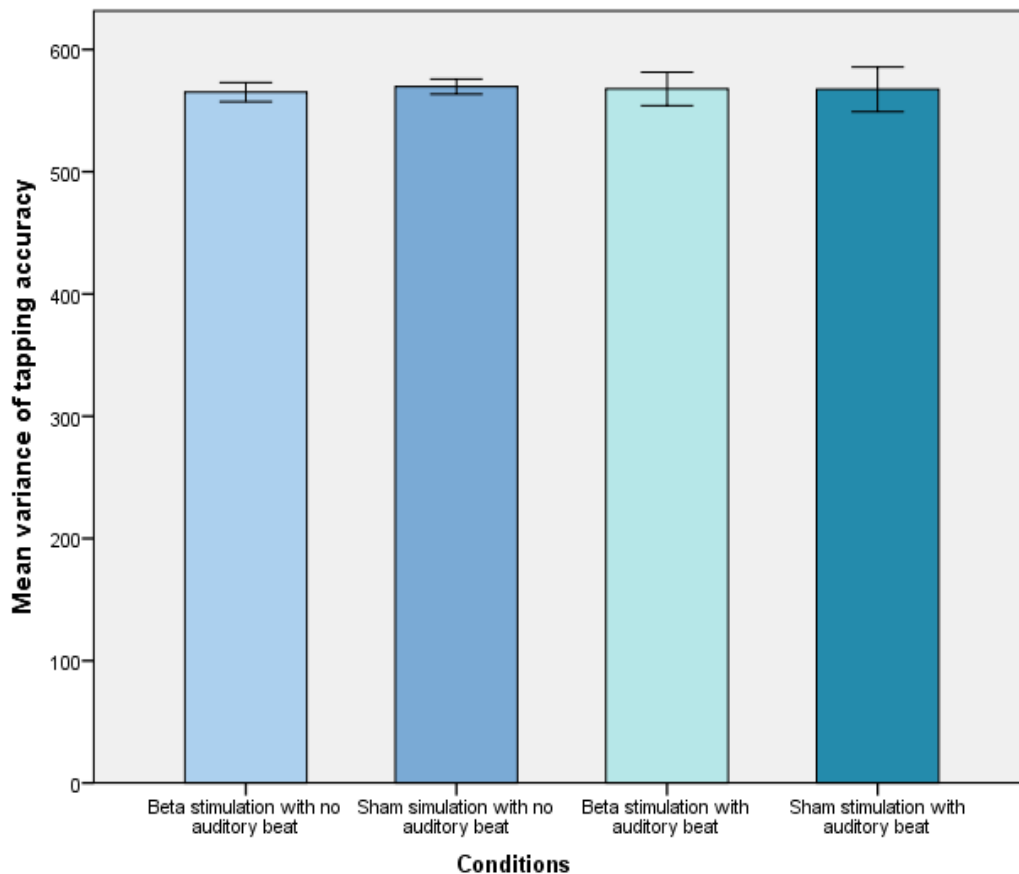


Figure 4. Bars represent the average of the variance of tapping accuracy across participants. Error bars are the 95% confidence intervals of the mean. NB the lower the variance, the more accurate- or more consistent, the tapping performance.

Discussion

Background

Excessive beta band oscillations observed within the basal ganglia of PD patients are presumed to be directly linked to the disorder's pathophysiology. As a result, it has been hypothesised that these pathological beta oscillations are causative of the motor symptoms characterised in the disorder (Kuhn et al, 2004). Patients with PD furthermore appear to have a specific impairment in movements that are self-initiated, such a paucity and/or slowness of voluntary movement (bradykinesia; IGM) (Wu et al, 2011). Whether a causal relationship exists between enhanced beta oscillations and a deficiency of movement, or whether beta has a specific impact upon IGM versus EGM, has yet to be established.

Aims of the present study

The present study aimed to discover whether externally enhanced beta oscillations in healthy subjects (administered via tACS) were causative for a reduced ability to tap along to an auditory beat. In addition, it aimed to further discover whether this externally enhanced beta has a more profound effect on IGM (tapping without an auditory beat) as opposed to EGM (tapping with an auditory beat). The results were analysed by means of two 2 by 2 repeated measures ANOVAs to distinguish any main effects or interactions.

Main findings

The analysis of the results revealed that neither stimulation (beta vs sham) nor tapping conditions (with vs without an auditory beat) created a significant main effect on either the mean tapping interval or variance in tapping accuracy. This suggests that beta stimulation did not have a direct impact upon tapping accuracy in comparison to the sham stimulation. Additionally, tapping accuracy was not directly influenced by the tapping conditions and no significant interaction was observed between both the stimulation and tapping conditions. This implies that the combination of beta stimulation and tapping with (IGM) or without (EGM) an auditory beat, also did not impact upon tapping accuracy.

H1: does beta administered via tACS reduce ability to accurately tap along to a beat

The analysis of the results indicated that there was no significant main effect of the stimulation condition on the participants tapping accuracy, therefore it appears that beta does not have a direct impact upon a deficiency of movement. As a result of this observation, this first hypothesis was rejected.

At face value, this finding appears to suggest that externally enhanced beta oscillations in healthy subjects are not causative for a deficiency of movement, this discovery could further extend to PD pathophysiology. Contrary to the general consensus, the results of the present study may indicate that pathological beta oscillations observed in PD patients are not directly linked with the motor symptoms characterising the disorder. Therefore, this is inconsistent with previous literature.

Correlations between exaggerated beta oscillations and the motor symptoms of PD have frequently been detected (Little et al, 2012; Pogosyan et al, 2010).

Furthermore, research conducted with the use of symptomatic treatments - such as DBS and L-PODA – have demonstrated a decrease in beta oscillation following clinical improvement of motor symptoms (Weinberger et al, 2006; Kuhn et al, 2008; Ray et al, 2008). Additionally, DBS of the STN at beta frequencies has also been revealed to worsen the motor symptoms (Eusebio et al, 2008; Chen et al, 2011). Thus, these findings furthermore highlight the link between pathological beta and motor deficiencies observed in PD patients.

Nonetheless, the non-significant result of the present study is in itself an interesting finding. The lack of influence the externally enhanced beta oscillations appear to have on healthy subjects may imply that beta generated via tACS is not equivalent to the power of the pathological beta observed in PD patients. Furthermore, it may also suggest that healthy subjects are better able to compensate for the enhanced beta and still produce accurate movements, whereas patients with PD may not have this capability.

However, before attributing the cause of the non-significant finding of the present study to the implications described above, reference to the work by Pogosyan and colleagues (2009) is necessary. When investigating the impact of externally enhanced beta (20Hz) in healthy subjects (administered via tACS), it was discovered that tACS was successful of artificially synchronising cortical activity in the beta frequency, and slow voluntary movement as a result (Pogosyan et al, 2009). Therefore, before concluding that externally enhanced beta administered via tACS is not directly linked to motor deficiencies - or that the impact of beta differs in healthy subjects – potential limitations of the present study's methodology should be considered.

These will be discussed further on.

H2: does beta have a specific impact on internally generated movements versus externally generated movements

Analysis of the results revealed no significant main effect of the tapping condition on the participants tapping accuracy. Furthermore, no significant interaction was observed between the stimulation and tapping conditions. Therefore, the second hypothesis was also rejected. This outcome appears to suggest that externally enhanced beta oscillations in healthy subjects do not have specific impact upon IGMs in comparison to EGMs. This discovery could again extend to PD pathophysiology.

PD patients appear to have a specific difficulty in producing IGMs. Bradykinesia (a paucity of movement initiation and execution), a cardinal symptom of PD, is particularly evident for IGM sequential movements and can benefit from the addition of an external rhythmic cue (Wu et al, 2011). Thus, one might have expected to have observed similar findings in the present study.

It was expected that beta stimulation alongside an absence of an external stimulus (without an auditory beat) would impair the participants tapping accuracy, whilst the addition of the external stimulus (with an auditory beat) may have in comparison facilitated performance. However, as previously stated, there was no difference observed following beta stimulation in either tapping conditions. This finding may indicate that enhanced beta oscillations are not a specific cause of poor IGM as opposed to EGM, and therefore, pathological beta oscillations are not a specific cause of poor IGM in patients with PD.

A lack of attention has been paid to the proposed definitive effect of pathological beta oscillations on IGM versus EGM. To the researcher's knowledge, this is the first attempt to examine the specific impact of enhanced beta oscillation on IGM in

healthy individuals. It was intended for these findings to lay the foundation for future study of IGM and beta in PD patients. If beta was successfully observed to have had a specific influence on IGM, it would infer that this is the cause of the predominant deficiencies in IGM characterised in PD.

Limitations of the present study

The present study indicates that externally enhanced beta oscillations in healthy subjects are not directly linked/causative for a deficiency of movement, and beta does not have a specific impact upon movements that are self-initiated (IGM). Furthermore, this finding may also suggest that pathological beta observed within PD is not causative for the motor symptoms, particularly in IGM. However, before concluding the above to be accurate, one must first consider the limitations of the present study.

The sample size of the current study is a methodological limitation as only eight subjects partook. Therefore, it could be insinuated that the current research has low statistical power. Low power refers to the low chance of discovering effects that are generally true (Button et al, 2013). Thus it could be contended that enhanced beta may actually possess a direct influence on motor deficiencies, but due to the limited sample, the link has gone undetected. In order to rectify this, the current study would essentially need be replicated with a much larger sample size.

In addition, one of the eight participants – by their own admission - was a skilled musician. It has been frequently discovered that in relation to motor timing, tapping along to a beat is more accurate in musicians as opposed to non-musicians (Franek et al, 1991; Krause et al, 2009). This may imply that this subject could have had a slight advantage on performance of the task, although, it is hard to say whether this would have had a substantial effect on the result. It would be assumed that externally enhanced beta oscillations would affect both the musician's and non-musician's motor cortex similarly regardless. However, this may perhaps be an interesting question to research in the future.

A further limitation of the current study may have been the appearance of retinal phosphenes during the beta frequency stimulation conditions. TACS has the ability to produce a strong enough current that passes through the eyes, and due to the sensitivity of the retina to electrical stimulation, this occasionally results in retinal phosphenes (subjective visual sensations) (Laakso and Hirata, 2013). The visibility of phosphenes elicited via tACS is dependent upon the frequency of stimulation (Kanai et al, 2008), but has a high likelihood of appearance specifically in beta frequencies (Antal and Paulus, 2013). Therefore retinal phosphenes should be taken into account when studying the cortical modulatory effects of tACS.

Seven of the eight participants reported experiencing retinal phosphenes. This may have compromised the intended concealment of the stimulation condition (beta or sham). If participants – as a result of the visual phosphenes – were aware of exactly when they were receiving the beta stimulation as opposed to the sham stimulation, they may have unintentionally/ intentionally altered their behaviour. Participants could have produced demand characteristics or may have attempted to increase their performance. Additionally, the appearance of retinal phosphenes may have

posed as a distraction leading participants to not attend ultimately to the task at hand.

A final limitation is linked to researcher error, and the setup of the experiment. The running of STARSTIM and MATLAB were required to be initiated concurrently. However, due to alternate loading speeds of both programs, the research observed on a few occasions that stimulation has seized before the auditory beats came to an end (MATLAB). As a result of this, it is possible that some data extracted under the beta stimulation condition was confounded as subjects may have not been receiving stimulation during the last collection of taps.

Future research

Improvements to the current study

The current study has the potential to be substantially improved by testing a much larger sample size of participants. If in fact a genuine link between enhanced beta band oscillations and a deficiency of movement exists, it is more likely to be detected with a greater sample size. Furthermore, it might be interesting to observe the effects that enhanced beta may have on different age ranges, and the effects upon both sexes individually. This study consisted of predominantly young individuals; perhaps looking at an older age sample (50+) would be more likely to produce noteworthy results as opposed to healthy young subjects. The present study's sample was also predominantly female with only two males participating. It might be interesting to have a sample equally split between the sexes to see if there are any observable differences.

If the present study's set up was to be bettered, both STARSTIM and MATLAB programs would need to be refined to fully ensure that they both start and end simultaneously to avoid any confounding data. Or, perhaps the addition of an extra minute to the running of STARSTIM, as the additional 20 seconds was not a long enough addition in few occasions. Finally, an increase in the complexity of the task may be beneficial for the study. Finger tapping tasks are frequently used to study the human motor system as they have the advantage of being simple enough in the study of both healthy participants, as well as those with motor disorders. However, seen as the sample was purely that of healthy subjects, it could be argued that finger tapping is too easy a task. An increase in complexity might be beneficial as participants would be required to pay closer attention to the task as hand, and therefore may produce different results.

Recruiting a sample who have a relative with PD

One area of future research could be the investigation into the link between enhanced beta oscillations and motor deficiencies, but in subjects who have a close relative with PD. Most cases of PD occur in people with no apparent family history of the disorder. These sporadic cases may not be inherited, or they may have an unknown inheritance pattern (Genetics Home Reference, 2012). Scientists estimate that around 1 in 20 cases of PD may be inherited, and current research is looking into the roles that genes may play in people developing familial PD (Parkinson's UK, 2012; Lubbe and Morris, 2014).

Therefore, it might be interesting to observe whether enhanced beta oscillations (administered via tACS) would have a different effect upon healthy individuals with a relative with PD, as opposed to those who do not. If some cases of PD are thought to be hereditary, it therefore may suggest that individuals who have a relative with PD may be more inclined to develop the disorder. Thus, it might be fascinating to observe whether there is a link between enhanced beta and motor deficiencies in this particular sample of individuals and if a link is discovered, decipher whether it is stronger in comparison to healthy individuals with no relatives with PD.

Deficits in motor timing

Deficits of motor timing in PD and its relationship with beta could be a further interesting aspect for future research. To summarise, evidence suggests that patients with PD show a dysfunction not only in the production of movement, but also in the timing of a movement. Deficits are consistent with a slowed “internal time clock” (Pastor et al, 1992). An internal time clock refers to the ability to estimate the passage of time without the benefit of cues from external clocks (Meck et al, 2005). Evidence suggests that beta oscillatory activity reflects timekeeping functions in healthy people (Fujioka et al, 2012), furthermore, Gulberti et al (2015) provide evidence for disturbed timekeeping functions directly linked to altered beta-band activity in PD. Therefore, it might be intriguing to assess the link between enhanced beta not only on deficiencies in motor production but also in motor timing, and perhaps a combination of the two.

Conclusion

The present study aimed to discover whether externally enhanced beta oscillations – administered via tACS – would impact upon the ability to accurately tap along to a beat. Additionally, to detect if beta would produce a more profound effect on IGM versus EGM. Analysis of the results did not find a significant main effect of either stimulation (beta vs sham) or tapping conditions (with vs without an auditory beat) on participants tapping accuracy. Therefore, these results show that enhanced beta in healthy subjects are not causative for a deficiency in movement.

This may suggest that pathological beta oscillations observed in PD may not be causative for the motor symptoms (particular bradykinesia) characterised in the disorder. Additionally, a significant interaction between stimulation and tapping conditions was not observed. This implies that beta may not have a specific influence upon IGM as opposed to EGM in healthy individuals, and extend those with PD. However, there were methodological limitations to the current study. Consequently, in order to discover a true causal relationship (if one should exist) between beta and motor deficiencies, improvements in the study would be necessary.

In summary, arising out of the present study, it appears that pathological beta band oscillations are not causative for the motor symptoms of PD, and that other mechanisms must be involved. Additionally, it suggests that beta is not causative for a deficiency in IGM as opposed to EGM. More research is evidently necessary in order to determine whether a true causal link exists, as the majority of literature proposes.

This area of research could be considered highly important. If a causal link is established between enhanced beta oscillations and deficiencies in movement within

PD, then research could potentially lead to the development of mechanisms to prevent extinguish and successfully cure the motor symptoms associated with PD.

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