An Investigation of multisensory integration: Does peak occipital beta frequency directly influence the Flash Tap illusion?

Jason Cooke

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Department of Psychology

University of Essex

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Abstract

Building upon a previous project this research looks to investigate a proposed relationship between the peak frequency of occipital beta and the temporal binding window (Cooke, Gillmeister, Romei & Wilson, In preparation) for the Flash Tap illusion first proposed by Violentyev, Shimojo and Shams (2005). Seventeen participants from the University of Essex underwent a TMS protocol in order to experimentally reduce their peak occipital beta frequency. Measurements for the temporal window were investigated Pre- and Post-TMS in order to ascertain whether changing the peak beta frequency also directly resulted in a change in temporal binding window size. Post-TMS beta frequencies were found to be significantly reduced compared to Pre-TMS measurements. Similarly, Post-TMS measurements of the temporal window were found to be significantly greater than Pre-TMS measurements. This suggests that in addition to a correlation between the two values peak occipital beta frequencies may directly influence individual temporal binding windows for the Flash Tap illusion.

Introduction

Our sensory modalities act as gateways through which we can interact with the outside world. Without the ability to see, feel and hear our environment it simply does not exist to us. Without these abilities we would be utterly unable to interact and navigate the world in which we live. The impact of losing access to even just one of these domains can be devastating. The magnitude of this can be highlighted by researchers who investigated patients suffering with a loss of sight, hearing or balance and found them to be suffering with significantly higher levels of detachment from their environment, as well as a significant detachment from their sense of self (Jáuregui-Renaud, Ramos-Toledo, Aguilar-Bolaños, Montaño-Velázquez & Pliego-Maldonado, 2008). As such it is clear to see that a greater understanding of our senses is hugely important. Understanding how we interact with our outside world gives us a greater knowledge into, not just our sensory domains, but also into healthy human behaviour as a whole.

Whilst it is often easy to think of our senses in isolation it is erroneous to think that the senses work independently of one another. Take for example the simple act of knocking upon a door. We can feel the wood from the door upon our knuckles, can hear the sound of the knock and can see our hand in front of us striking the door. However, we do not simply experience all of these as separate actions, we attribute them to one single perceptual whole. This is thanks to a crucial neural mechanism known as multisensory processing. Multisensory processing is the means by which information from different sensory domains are integrated into one perceptual whole, this process is often associated with the superior colliculus, however other areas of the brain have also been discovered to process this information (Meredith & Stein, 1986), something that will be discussed later in this report.

Multisensory processing is predominantly important in producing a coherent picture of our environment based on the different combinations of the sensory information we receive. Without this process our world becomes a frightening and disorientating place. Examples of this can be seen in disorders of the multisensory system, one such being sensory integration dysfunction (Goldstein & Morewitz, 2011). This disorder is surprisingly common, with around 15% of all children experiencing some form of the condition to some degree (although it is often undiagnosed and subsequently grown out of with little to no lasting problems). Sensory integration dysfunction has been known to cause learning or behavioural problems or extreme and uncontrollable anxiety due to the inability to combine information from different sensory domains (Stepp-Gilbert, 1988). Thus here we can see that without the ability to bind sensory information the world does indeed become a strange and confusing place.

Another example of a dysfunctional multisensory processing system comes from a bizarre condition known as synaesthesia which affects around 1% of the population (Saenz & Koch, 2008). With this condition the multisensory pathways have become scrambled, meaning that often a sensory stimulation in one domain will evoke a secondary stimulation in an irrelevant secondary domain (Cytowic, 2002). For example, a sufferer may hear a particular piece of music and in fact also see the music just as clearly as they hear it. This condition has been found to be fairly flexible in terms of which modality is affected and with is the affecting modality. For example, Beauchamp and Ro (2008) investigated a patient suffering with a thalamic lesion as the result of a stroke. This patient reported feeling an intense tingling sensation upon their skin at the presentation of certain sounds. Other examples include visuo-auditory synaesthesia, whereby the patients were presented with a flash that induced the perception of a sound (Saenz & Koch, 2008) and visuo-tactile synaesthesia whereby the patient experiences the feeling of being touched when merely viewing another individual being touched. (Blakemore, Bristow, Bird, Frith & Ward, 2005).

Essentially what synaesthesia and sensory integration dysfunction tells us is that multisensory processing is an important process when it comes to interacting with our environment When this mechanism breaks down or begins working abnormally often what results can be intensely disorientating. However according to recent theories the importance of multisensory processing may go beyond that of mere perception, it may play a role in other neurological conditions that can potentially affect all aspects of the quality of one's life.

There exist many examples in recent literature linking a degradation of the multisensory system to a plethora of neurological and even some more physical conditions. One example of this comes from a piece of research conducted by Ross et al., (2007), who linked poor multisensory processing to schizophrenia. The researchers found that patients suffering with this condition find it very difficult to perceive speech and mouth movements together, this is despite unisensory speech perception being intact and almost indistinguishable from healthy controls. Another example of this comes from autism where altered multisensory processing has again been found (Kwakye, Foss-Feig, Cascio, Stone & Wallace, 2011) with those suffering with the condition also demonstrating an enlarged multisensory temporal binding window (Foss-Feig et al., 2010). In this case the temporal binding window represents the maximum time delay between two pieces of stimuli whereby information can be combined into one perceptual whole. Finally, a link between eating disorders and altered multisensory processing has also been uncovered, this includes anorexia nervosa (extreme weight loss) which is associated with an impairment in multisensory body perception (Gaudio, Brooks & Riva, 2014). This is alongside obesity (extreme weight gain) where, similar to autism, a wider temporal binding window has been found (Scarpina et al., 2016). This is alongside a number of other multisensory disturbances, including an abnormality in the perception of both taste and smell (Pasquet, Frelut, Simmen, Hladik & Monneuse, 2007) and the breakdown of multisensory body perception (Harriger & Thompson, 2012).

These examples elucidate a greater incentive for us to investigate multisensory processing. A greater understanding of the underlying systems behind multisensory integration would not just look to increase our understanding of the system itself, but may also in the future be used to provide a form of treatment or intervention to some of these debilitating conditions.

What these conditions ultimately tell us is that it is important to study both unisensory perception and multisensory perception in order to obtain a more comprehensive understanding of how we interact with our world and how our world interacts with us. However, historically research into the various senses has focused almost exclusively on investigating them in isolation of one another, that is they focused almost entirely on unisensory processing. Up until the last 20 years' investigations into multisensory processing were relatively rare (although not unheard of), this could be attributed to the traditional view that senses were functionally separate from one another within the brain. As a result, the brain was often simplified and compressed into a series of unisensory systems that work exclusively in isolation. As such it was often thought of as futile to investigate the sensory systems in anything other than in terms of unisensory processing (Kayser & Logothetis, 2007).

However, research subsequent to this has since provided strong evidence that this is not in fact the case, and our senses do in fact operate within more of a multisensory framework (Calvert, Spence & Stein, 2004). Essentially this means that there are systems within the brain that respond to more than one type of sensory information. Evidence for this comes from a number of investigations. As mentioned one such area strongly implicated is the superior colliculus (Meredith &

Stein, 1986), these researchers investigated this area via the use of cats, and found many different types of sensory information appear to be processed here (Meredith & Stein, 1983; Meredith & Stein, 1986; Meredith, Wallace & Stein, 1992). Another example of a multisensory area of the brain comes from an investigation by Watkins, Shams, Tanaka, Haynes & Rees (2006) who found that when a participant was presented with a brief noise they were able to induce activity in both the auditory cortex (which obviously should be expected) and yet more surprisingly the visual cortex (specifically area V1). This suggests that V1 may in fact be an area that deals with multisensory information. Similar results were found in other numerous investigations where again it was found that multisensory activation took place in both the visual and auditory cortices as well as some fronto-temporal regions (Giard & Peronnet, 1999) along with other parieto-occipital areas (Molhom et al., 2002). Investigations into visuo-tactile processing have uncovered even more potentially multisensory areas of the brain, in the case of a study conducted by Ehrsson, Holmes and Passingham (2005) the ventral premotor cortices, intraparietal cortices and the cerebellum were all found to be activated when investigators utilised a visuo-tactile task.

It is important to note that many of the investigations into multisensory processing focus on illusions bought on by exploiting the systems we use to combine multisensory information. However, what is thought of as the first investigation into this phenomenon focused predominantly on something far more mundane; the simple act of speaking. When we listen to someone enunciating a word or a sentence it is easy to assume that it is only our ears and our auditory system that is doing the work, however this is simply not the case. We also utilise our visual system in order to enhance our speech comprehension, this is something that becomes abundantly clear when we watch and attempt to listen to a poorly dubbed foreign film where the lip movements do not match up with the speech patterns. Often it becomes a lot harder to understand what the onscreen actor is saying simply because of the incongruency between what is being said and the specific movements of the mouths of the actors we can see. This example of how our visual and auditory systems can combine forms the basis of the seminal paper on multisensory integration.

Sumby and Pollack (1954) investigated speech comprehension by asking participants to simply listen to a person speaking, this was whilst varying the level of background noise in one of two experimental conditions. In one of these conditions participants had to perform a speech intelligibility task whilst the speaker hid their mouth movements, in the other condition the participants underwent the exact same task with the speaker's mouth in full show. Sumby and Pollack (1954) demonstrated that utilising both auditory and visual information was beneficial to speech comprehension, especially when compared to simply utilising auditory information in isolation. Participants who could view the speaker's mouth performed the intelligibility task significantly more accurately (40 – 80% of words identified correctly) than their counterparts who could not view the mouth (less than 20% of words correctly identified).

The research into speech intelligibility by Sumby and Pollack (1954) can inform us of just how much we rely on our multisensory system in order to understand the world in which we live. But perhaps the true magnitude of how we rely on a combination of sound and vision in the perception of speech can be highlighted by a famous and oft cited illusion. This phenomenon demonstrates just how much our understanding of speech relies on vision by demonstrating how our perception of auditory information can be warped entirely by incongruent visual information. The McGurk Effect (McGurk & McDonald, 1976) is a famous illusion whereby participants are presented with video footage of an actor saying the nonsense phrase "ga-ga". Paired with this visual lip movement is the sound of an entirely incongruent speech sound, that of a person saying "ba-ba". Interestingly when these two pieces of differing stimuli are paired together participants often report hearing the person actually saying "da-da", which is in fact an amalgamation of the two pieces of information. This further demonstrates how hearing and vision can interact with one another in the perception of speech.

Whilst some of the most obvious and most salient examples of the cross-modality of our senses include the interaction between our visual system and our auditory system, it is by far the only example of this phenomenon. In fact, the cross-modality between our visual and our tactile systems may be vital in helping people who are suffering with blindness to read. Some sources within the literature report tactile information being processed by areas of the brain thought to be solely unisensory (Amedi, Malach, Hendler, Peled & Zohary, 2001) and one example of this occurring happens when a person loses their sight and learns to read via Braille. Braille is a reading system created by Louis Braille in 1824, it is a system specifically developed for the blind, enabling them to read text via a series of raised and coded bumps. Essentially it appears to allow patients to forgo their faulty or redundant visual system and allows the tactile system to take over the act of reading. However, things are not nearly as simple as this, as has been highlighted by a study conducted by Sadato et al., (1996). This study utilised positron emission tomography (PET) in order to investigate the areas of the brain being activated when Braille was processed by blind participants. It was found that whilst there was a normal level of activation in the somatosensory cortex there was also an increased level of activation within the visual cortex. Interestingly there was also a change in activity in sighted controls, who conversely experienced a reduction in neural activity across their visual cortex. Researchers hypothesise that the neural plasticity of the brain enables it to exploit multisensory pathways (possibly via the lateral geniculate nuclei) in order to provide this compensatory tactic and effectively enable the blind to “see” (Sadato et al., 1996). Interestingly this system appears to be relatively easy to exploit. Pascual-Leone and Hamilton (2001) investigated the teaching of Braille in sighted participants who had been blindfolded. After only 5 days’ participants began to exhibit activation in the primary and secondary visual cortices when feeling the Braille, similar to the processes observed in the blind participants. Perhaps even more interestingly an auditory-visual (and auditory-visual) counterpart to this effect can also be found, where visual, (or even in some cases somatosensory) information provokes a response in the auditory cortex of congenitally deaf adults (Karns, Dow & Neville, 2012).

As mentioned much of the research conducted on the cross-modality of our senses looks at illusions and how by exploiting certain aspects of how information is usually combined we can warp the world around us by introducing inconsistencies or incongruences into the process. However much like with the McGurk Effect, historically investigations have focused upon illusions whereby vision has an effect upon another sensation. This could be hearing, such as with the McGurk Effect or the Ventriloquist Effect. The Ventriloquist Effect is an illusion whereby our perception of where the source of a sound is altered by the visual stimulus associated with that sound, leading to a mislocalisation of its source of origin (Bertelson, Vroomen, De Gelder & Driver, 2000).

Examples also exist where vision can have an illusory influence upon the sensation of touch. This can be demonstrated in an illusory effect known as Visual Capture with perhaps the most well-known example of this being the Rubber Hand Effect. Here a participant will have their own hand hidden from view, often behind a large screen or beneath the table, and a realistic rubber hand planted in its place. From here a researcher will begin to stroke both hands with a paintbrush, providing tactile information (in the form of the sensation on the real hand) and visual information (in the form of the stroking action upon the fake hand), these are both incongruent to one another. As a result, participants will begin to feel that the fake hand is actually an extension of their own body, completely replacing the real hidden hand. The effect can also be so strong as to cause the participant to flinch away, fearing pain, if their fake hand is struck with a hammer or a heavy object (Botvinick & Cohen, 1998; Pavani, Spence & Driver, 2000).

The reason for conducting so many investigations on the influence of vision on our other sensory domains is often attributed to the somewhat archaic view that vision is the dominant domain (Posner, Nissen & Klein, 1976; Heron, Whitaker & McGraw, 2004). However, research conducted within the last 20 years has demonstrated that this is not in fact the case and that vision is perhaps not as dominant as it was once thought of (Shams & Kim, 2010). One of the first examples of vision falling victim to the illusory effect of another sensory domain comes from Sekuler, Sekuler and Lau (1997) who demonstrated how a sound can influence the perception of a visual stimuli. These researchers presented participants with a simple task, they were shown two balls on a screen, these balls began to slowly move towards one another, until they appeared to completely overlap before stopping at the other side of the screen. Here participants were asked to say whether, they thought the balls streamed through or did they collide and bounce off of one another. Due to the ambiguity of the stimuli there was no correct or incorrect answer, however most participants stated that they believed the balls had streamed through one another, this was found to be the case on around 87% of trials (Sekuler & Sekuler, 1999). This is thought to be due to our visual system's overall bias towards continuity and the smoother motion that continuity entails (Vitello, 2010). Interestingly however, when a brief tone was played at the same time the balls met participants often changed their view, (despite the visual stimulus remaining the same) and stated that the balls this time bounced off one another. Here the participants had used their multisensory system to combine the visual information and the auditory information, assuming that the sound they heard represented the sound that the two balls made as they bounced off of one another.

A similar influence upon an ambiguous visual task has also been demonstrated to occur within the tactile domain as well. Ernst, Banks and Bülthoff (2000) demonstrated that when briefly presented with an object and asked to judge its overall level of slant, a participant's response may be heavily influenced by a brief tactile stimulation or haptic feedback that is presented concurrently to the presentation of the visual stimulus.

Most of the examples presented thus far require participants to make subjective judgements, that is they are all based on non-quantitative responses and are as such difficult to reliably falsify. This does raise the question of whether similar cross-modal effects can be expected for more objective, unambiguous tasks where an answer can either be correct or incorrect. This issue was indeed tackled by Shams, Kamitani and Shimojo (2000) and later replicated by Shams, Kamitani and Shimojo (2002), in an illusory paradigm that requires a more unambiguous response. These researchers investigated a phenomenon known as the Flash Beep Illusion and it is this illusion that forms the basis of this current research. With this illusion the researchers presented participants with a disc upon a screen, this disc would always flash once and subsequently disappear. It was the job of the participant to state to the researchers how many times the disc flashed. Given that the disc will always flash once obviously the correct answer should always be "one", hence the reduced subjectivity of this task. With all explicit tasks however some subjectivity remains, however with the introduction of a “correct” and an “incorrect” answer the task is automatically more objective than its predecessors.

Whilst the task may seem very easy at first glance, incongruent auditory information was presented alongside this single flash. In this case the presentation of the flashing disc is always paired with a quick double beep. When the flash is paired with this double beep, participants can often be convinced that the disc flashed twice, when participants give this answer it is clear that they have fallen victim to the illusory effect and have hence provided the incorrect answer. This effect has been called a fission illusion, as the flash has essentially been split apart into two, interestingly there is also a corresponding fusion illusion whereby two flashes essentially fuse into one when a single beep is presented, this effect has been found to be significantly weaker than the fission illusion (Shams et al., 2002).

Interestingly in a later follow up study conducted by Violentyev, Shimojo and Shams (2005) it was found that a corresponding tactile counterpart of this illusion existed, this effect was named the Flash Tap Illusion. Unsurprisingly, given its name, participants were again given the same flashing disc (again one that only flashes once) and were asked again to count the flashes. Similar to the previous task participants could yet again be induced into seemingly perceiving two flashes when their index finger was tapped twice in quick succession, this was of course at the same time as the visual stimulus was presented. As before alongside this fission illusion there was also a corresponding fusion illusion that was yet again found to be significantly weaker than its fission counterpart (Violentyev et al., 2005). Interestingly further research uncovered a similar effect when active touch based tasks were used, that is where participants had to actively move their hands to touch a keypad (Kunde & Kiesel, 2006). Here even when the participants tapped a keypad themselves they could again be induced into perceiving two flash where once again only one is present.

As such from this research it is easy to see how the previous view that the visual domain is dominant and hence cannot be influenced by other domains is incorrect. Furthermore, this research demonstrates that the effect can be so strong that it can have a pronounced significant effects on not just subjective tasks but on more objective, less ambiguous tasks. As such this research led to a new way of looking at the senses and how they act cross-modally, this influence forms the basis of the current research being discussed here.

Specifically, this research focuses mainly on what is known as the temporal binding window. This was something that Shams et al., (2002) also focused on in their research on the Flash Beep Illusion. Essentially in this respect the temporal binding window relates to the spacing of the beeps, more specifically the maximum temporal spacing that induces the illusion. The researchers investigated this by carefully varying the interstimulus interval (ISI) between the beeps, eventually finding the temporal binding window for this illusion to be on average between 70 – 115 ms, roughly 100 ms. This means that when the two beeps are spaced apart by less than 100 ms on average participants tend to report seeing two flashes, suggesting the illusory effect is taking place. However, when beeps are spaced apart by more than 100 ms the illusory effect begins to degrade and the participants will tend to report seeing only one flash.

Surprisingly (and somewhat disappointingly) this information was not provided by the researchers in the corresponding investigation of the Flash Tap illusion (Violentyev et al., 2005), however currently unpublished research has suggested that the temporal window for the Flash Tap illusion may be slightly longer than that of the temporal window for the Flash Beep illusion. One investigation of 14 participants indicated that with an average temporal binding window of 100.4 ms for the Flash Beep illusion a window of 118.4 ms was found for the Flash Tap illusion. For another investigation of 17 participants a slightly shorter window of 86.9 ms was found for the Flash Beep window, and yet again a slightly higher value of 92.9 ms was found for the Flash Tap window for the same group of participants (Cooke, Gillmeister, Romei & Wilson, In preparation). This is perhaps unsurprising given the findings of Bresciani, Dammeier and Ernst (2008) who found that the tactile counterpart to this illusion tends to be somewhat noisier compared to the auditory counterpart. Perhaps this is due to the more diffuse nature of touch. In other words, touch is something that is felt all over the body. For example, even though one hand was stimulated, participants would still have had feeling upon the other hand, perhaps they could feel the cold table on their resting hand, not to mention various other potential sensations felt all over the body.

As such the sensation of touch is constantly being confounded by irrelevant information across the body. Whereas it is relatively easy to control for auditory confounds, firstly it is only confined to the ears giving a smaller area of stimulation. Secondly it is much easier to simply control for other sounds in the lab, a simple quiet room is all that is needed to remove most confounds of this nature. It is nowhere near as simple as this for the tactile domain as it is difficult (perhaps impossible) to remove the irrelevant tactile information that may confound the results.

Further to this, there have been conflicting findings as to the relationship between these two windows. The previously mentioned unpublished work also attempted to shed some light on any potential relation between them. The first investigation (N = 14) found a significant, very strong positive relationship (r = .85). Perhaps surprisingly given the previous strong finding the second investigation (N = 20) found a weak, non-significant relationship (r = .35), there is clearly a lot of noise present in this relationship, hence highlighting the need for further investigation into this phenomena (Cooke et al., In publication).

Essentially this research will look to build upon and supplement work previously conducted on the Flash Tap and Flash Beep Illusions that is as yet unpublished (Cooke et al., In publication). These researchers have demonstrated a link between the temporal window for the Flash Beep illusion and an individual's peak alpha wave frequency (something that had already been uncovered in the literature). Alongside this the researchers also provided tentative evidence for a relationship between the temporal window for the Flash Tap illusion and an individual's peak beta wave frequency in the visual cortex. Essentially signalling a functional difference between the temporal binding windows for these two illusory effects.

The basis for these findings originated from a piece of research conducted by Romei, Gross and Thut (2012) who had already demonstrated that there was a link between an individual's alpha band responses in the visual cortex and visuo-auditory multisensory integration. This was conducted even before there was a suggestion of a link between the alpha frequency and the temporal window specifically. The alpha wave typically covers oscillations between 7.5 – 12.5 Hz, with an average frequency of around 10 Hz. This wave is typically associated with attention and memory processes (Klimesch, 2012). It has also been linked with idling, or resting periods and as it originates from the occipital lobe it also is linked to visual processes, this can be observed when a participant closes their eyes and the alpha activity decreases (Palva & Palva, 2007).

Romei et al., (2012) successfully demonstrated that there was a link by presenting participants with a brief tone, due to what was stated to be neuro-oscillatory entrainment, the alpha band responses in the visual cortex could be reset. Essentially this demonstrates that an auditory stimulation could have an influence on the neuro-oscillatory responses in the visual cortex. The researchers suggested that the mechanism by which sound modulates visual perception (for example in the Sumby and Pollack (1954) task) is by phase-locking with the alpha phase in the visual cortex. Interestingly some other sources have since linked the alpha wave with auditory processes, which may explain the link between the visual cortex, the auditory cortex and the alpha wave (Müller et al., 2013; Schlee et al., 2014).

This research by Romei et al., (2012) was subsequently developed upon by Cecere, Rees and Romei (2015) who explicitly linked the Flash Beep illusion to the alpha phase, by providing direct evidence of a correlation between the two values. The researchers asked participants to undergo the same Flash Beep task as performed by Shams et al., (2002) whilst undergoing a full electroencephalogram (EEG), they used this to specifically investigate the alpha band activity in the visual cortex as the participants were taking part in the illusory task. Cecere et al., (2015) tested 22 participants and found that there was a significant positive correlation between the temporal window for the Flash Beep Illusion and the individual alpha wave time phase. This relationship was found to be moderately strong (r = .697). Essentially this means that if one individual had a slower alpha wave (and hence a lower frequency), their temporal window was likely to be longer than those who had a faster individual alpha wave.

Further to this interesting finding Cecere et al., (2015) were able to go one step further and provide direct evidence of a causal relationship between the two variables, essentially they demonstrated that the alpha frequency appears to directly influence the individual temporal window for the Flash Beep illusion. They did this via the use of transcranial alternating current stimulation (tACS), they used this method to modulate alpha band activity across the participants' visual cortices, however they did not stimulate at the exact frequency of occipital alpha, but they stimulated each person's individual alpha frequency plus or minus 2 Hz. They managed to directly change the participant's individual occipital alpha frequency by stimulating either 2 Hz above this value or 2 Hz below it, allowing them to directly slow down or speed up the alpha wave. By doing this Cecere et al., (2015) were also able to experimentally manipulate each individuals' temporal binding windows, when the alpha frequency was reduced the temporal window widened, conversely when the alpha frequency increased, the window shortened. Demonstrating that it may be the case that the two variables are not simply related but that occipital alpha frequency may directly influence the properties of the Flash Beep window.

Since the publication of these interesting findings a further investigation was carried out last year in order to provide further details of this relationship (Cooke, et al., In publication). Firstly, the researchers looked to replicate the relationship between the alpha frequency and the temporal window for the Flash Beep illusion. Secondly the main aim of the researchers was to look to investigate any potential relationship between the alpha frequency and the temporal window for the Flash Tap Illusion. In order to provide a full picture of any correlation the relationship between the individual beta frequency and the temporal window and the relationship between the individual theta frequency and the temporal window was also investigated (Cooke et al., In publication).

The beta wave typically covers a frequency range of 12.5 – 35 Hz and can in fact be split into 3 distinct wave bands: low beta (12.5 – 16 Hz), mid beta (16 – 20 Hz) and high beta (20 – 35 Hz) whilst some sources are inconsistent on where beta begins and ends, 35 Hz tends to be the absolute maximum whereby beta is considered (Rangaswamy, et al., 2002; Foffani, Bianchi & Baselli, 2005). This neuro-oscillatory process is prevalent during tasks which require large amounts of concentration**.** Alongside the alpha wave, the final wave form that was investigated was the theta wave. The theta wave typically exists within the range of 4 – 7 Hz, cortical theta tends to indicate a relaxed, meditative or drowsy state, usually during sleep (Cajochen, Foy & Dijk, 1999), they can also reflect cognitive and memory performance on certain tasks (Klimesch, 1999).

As was expected the relationship between the alpha frequency and the Flash Beep window was replicated ($r = .636$). Further to this no other relationships between this value and any other individual frequencies were found. Interestingly no relationship was found between the alpha frequency and the window for the Flash Tap illusion ($r = -.026$) which was something of a surprise, there was also no correlation between the window and the theta frequency. However, a somewhat surprising significant correlation between the beta frequency and the Flash Tap window was found ($r = .73$). This was an unexpected result that led to a number of possibilities as to why this would be the case, one such possibility is that certain multisensory areas of the brain tend to process pieces of information differently when the multisensory task requires different information from different domains. For example, as already stated alpha band responses have been linked to auditory processes, as such perhaps in this case the visual cortex is drawing upon the alpha band in order to process visuo-auditory information. Interestingly sources tend to implicate beta waves in muscle contractions and other tactile tasks (Baker, 2007) also other more complex somatosensory tasks have been implicated, such as the execution, anticipation or recovery of body movements (Foffani, et al., 2005). Again this may also provide an explanation for the link between the Flash Tap window and the beta frequency. Somewhat similar to before the visual cortex is drawing upon the beta wave (rather than the alpha wave) in order for it to process the visuo-tactile information being presented.

Obviously this theory is very much a tentative approach to explaining the findings, and without further investigation is nothing more than a mere hypothesis. However, this does provide ample justification for us to conduct the research currently being discussed.

This current research will look to build upon the somewhat surprising result that was found in the previous investigation (Cooke et al., In publication), that is the relationship between the beta frequency and the Flash Tap window. We will attempt to firstly replicate the previous relationship and then hopefully provide evidence of a causal relationship between the two. We will also look to further replicate the relationship between the alpha frequency and the Flash Beep window found by Cecere et al., (2015). Alongside this we will also look to provide more information about the Flash Tap illusion by interchanging the hands that the stimulation is taking place. Finally, we will attempt to shed some more light on a novel technique of neuromodulation, this final aspect will be discussed later.

What will happen in this research is as follows: participants will undergo both the Flash Beep and the Flash Tap tasks, whilst undergoing a full EEG, this will be done so that the alpha, beta and theta frequencies can be found across the visual cortex. Incidentally participants will actually undergo two different Flash Tap trials, one where the tactile stimulation takes place on the left hand (this is the hand that most sources in the literature tend to stimulate (for example, Violentyev et al., 2005)) and another on the right hand. We will also again look to investigate the relationship between the Flash Tap Illusion and the Flash Beep Illusion. From here the relationships between the alpha frequency and the beep window and the beta frequency and the tap window will be investigated (as well as any investigation with the other two respective frequencies; alpha and theta). If the replication of the correlation between the beta frequency and the tap window is successful participants will then subsequently undergo a brief 15 minute transcranial magnetic stimulation (TMS) protocol. This protocol will aim to stimulate the connection between the somatosensory cortex on the right hemisphere and the visual cortex. The stimulation will look to modulate the frequency which equates to the participant’s individual beta frequency minus 3 Hz, essentially we will be looking to experimentally slow down the beta wave time phase. We will look to slow the wave down as this is the natural progression as a result of aging, aging is often linked with a slowing down of neuro-oscillations. We will then ask the participants to perform the Flash Tap illusion trials (both for the left and the right hand) once more in order to investigate the respective temporal windows and uncover any potential experimental changes.

The TMS protocol that we are using is a relatively new method, that has as yet not been used in this particular fashion, and as such this investigation will look to provide further information about this novel method of stimulation, which is called Cortico-cortical paired association stimulation (CCPAS). CCPAS was a technique developed by Rizzo, et al., (2009), it is a relatively new method of using TMS in order to produce Hebbian like processing (Rizzo, et al., 2011; Buch, Johnen, Nelissen, O'Shea & Matthews, 2011). This works by stimulating pre- and post-synaptic cells, much in the same way Donald Hebb theorised that connections between two neurons are made (Hebb, 1949). Essentially by stimulating two areas of the cerebral cortex researchers are able to induce the same neuro-chemical processes that take place during the process of long term potentiation (LTP), enabling them to exploit the process whereby long term memories or learning takes place. This enables researchers to create semi a-permanent connection between two interconnected areas of the brain (Koganemaru et al., 2009). Most of the current research using CCPAS looks to modulate motor based processes (Rizzo, et al., 2009; Koganemaru et al., 2009; Rizzo, et al., 2011), much like we are using in the current study protocol. Recent research has since moved on to investigate this process in terms of visual processes. Romei, Chiappini, Hibbard and Aventanti (2016) used this method to stimulate between Visual Area 5 (V5) and Visual Area 1 (V1) in order to provide a perceptual enhancement. However, the idea of using this method to modulate a connection between two functionally different areas of the brain is relatively unique, with the few studies that do deviate from stimulating between the right and left motor cortex (M1), other than Romei et al., (2016), tending to stimulate between the ventral premotor cortex (PMv) and M1 (Buch, 2011; Johnen et al., 2015).

Furthermore, the usage of the stimulation is also unique. We are stimulating at a time separation based solely upon the theory that the proposed connection is based upon a travelling wave. We are then using the unique method of manipulating the stimulation based upon each individual participants' unique travelling wave properties. Typically, when using this method, the time delay between the two stimulations is much shorter in order to correspond to pre and post synaptic stimulations. Romei et al., (2016) demonstrated some success when using a slightly longer time delay with this method and it is hoped that we are able to replicate this success whilst utilising an even longer delay. Whilst perhaps the usage of this method is somewhat ambitious (and arguably a large risk), any success would provide a greater understanding of the method of CCPAS and also an understanding of the potential uses. Should stimulation in this regard not be successful potential safeguards could be put into place. For example, if no change in beta frequency is detected an alternative method could be utilised. For example, the study could change in order to utilise tACS, which is the method utilised by Cecere et al., (2015) which was successfully used to modulate the alpha band, producing a corresponding change in the temporal window for the Flash Beep illusion. This would allow us to forgo the use of the CCPAS method in this respect but still allow us to investigate our hypothesis.

In conclusion this investigation aims to provide a comprehensive investigation of the Double Flash Illusion, most notably the Flash Tap component. It will also look to provide an insight into a relatively new method of neuro-stimulation. Given by how much will be investigated here this study will be split into two distinct investigations. In investigation one we will be looking at the relationship between the alpha frequency and the temporal window for the Flash Beep illusion. In line with previous research we would expect this relationship to again be positive and moderate-to-strong, furthermore we should expect to find no correlations with this window and the beta and theta frequencies. We will also be investigating the relationship between the beta frequency and the temporal window for the Flash Tap illusion, again we should expect to see a moderate-to-strong positive relationship between the two. As before we should also expect to not find any other correlations between this window and the alpha and theta frequencies. Finally, in investigation one we will also attempt to shed some more light upon the relationship between the temporal windows for the Flash Tap Illusion and the Flash Beep Illusion. It is somewhat difficult to know what to expect from this as past investigations have been mixed. We will look at this information both in isolation, and in combination with the results gathered last year, due to the identical method of investigation.

Investigation two will focus exclusively upon the Flash Tap Illusion and will firstly look to provide some more information on handedness in terms of this illusion. We will find out the temporal windows for the illusion for the right hand and the left hand. It is unknown as to what we find, but perhaps should be logical that we should expect handedness to make little-to-no difference, if this is the case we should expect to find no significant difference between the two. Furthermore, the two windows should subsequently be highly correlated with one another. If the expected correlation between the beta frequency and the Flash Tap window is found, we will then perform the 15 minute CCPAS protocol and investigate the neuro-oscillatory changes and any (potential) behavioural changes that result from this. If our stimulation of the participants' cortices is successful we should expect to find a significantly reduced individual beta frequency post-stimulation across the visual cortex (compared to the pre-stimulation beta frequency) when the participant performs the Flash Tap task. This should only be the case for the left hand however as, due to the contralateral nature of the human brain, our stimulation of the right hemisphere should only affect the left hand. Furthermore, we should expect to find no difference between the left hand and right hand pre stimulation, however this should not be the case post-stimulation, as the left hand task should yield a significantly lower beta frequency.

Should our stimulation be successful we would then need to specifically investigate the behavioural responses associated with any neuro-oscillatory change in the visual cortex. As such we would hope to see a significantly larger temporal window post-stimulation (compared to the pre-stimulation window) due to the change in individual beta frequency. As before this difference should not exist for the right hand. Furthermore, we would hope to see a significant difference between the right Tap window and the left Tap window for the post-stimulation investigation, again suggesting that any change only took place on the expected left hand. The final investigation that will be carried out will look to investigate the nature of any changes. We would look to directly correlate any change in the left Tap window and the change in beta frequency. Essentially we would hope the two to be correlated as this would suggest that any change in behaviour was directly linked to a corresponding change in the beta frequency.

Experiment One

Methods

Participants

67 participants were recruited via a volunteer system, all of the participants were students studying at the University of Essex. The age range was 18 – 36 (median: 21) and the sample included a mixture of males (22) and females (45). Out of the 67 participants 63 were right handed, 3 were left handed and one participant identified as being ambidextrous. None of the participants had any known hearing or tactile impairment that would have affected their perception of the stimuli. All participants' vision was normal or corrected to normal via spectacles or contact lenses.

A practice trial was included prior to the study to ensure that all participants saw both the Flash Tap and the Flash Beep illusion, as with any illusion there is some variability in individual participant's proneness to its effect. After this the best 25 participants were selected, this was based on the strength of the illusory effect and the consistency across trials and across different illusion (i.e. Flash Beep and Flash Tap). The age range of this new sample was 18 – 24 (median: 21). Again a mixture of males (11) and females (14) were used. Twenty-three of the participants were right handed with the remaining 2 being left handed.

As part of this study was looking to build upon a previous pilot study some of the analyses used participants from both sets of samples (from the pilot and the current experimental study). These participants were treated exactly the same way, underwent the same procedures and all met the same selection criteria as those in the experimental study. There were 17 participants in the pilot study, when combined with the participants from the current sample this means that there was a total of 42 participants. The age range of the total sample was 18 – 44 (median: 22), with 26 participants being female and the remaining 16 being male. All of the participants that took part in the original study were right handed meaning the total ratio was 40:2 in favour of right handedness.

Apparatus

The participants were presented with the visual flash stimuli via a Dell Optiplex 960 computer (running Windows XP) on a Viewsonic Graphics Series G90fB cathode ray tube (CRT) monitor at a resolution of 1280 x 1024 and a refresh rate of 85 Hertz (Hz). For the presentation of the auditory stimulus and the white noise a pair of Nicole Flat USB speakers were placed either side of the monitor. For the presentation of the tactile stimulus a Heijo Research Electronics tactile stimulator was placed upon the left index finger of the participant. Participants were presented with the experimental stimulus via the computer programme E-prime (version 2.0). The inputting of responses was performed by the experimenter via the use of the computer's keyboard, with only the "1" and "2" key being used. The EEG scanning was done via the computer programme Brain Vision Recorder (Brain products) with the use of an Easycap EEG cap and a Brain vision professional Brainamp. The data was analysed via the programme Brain Vision Analyser (version 2.0). Sixty-four EEG channels were used for this investigation, alongside a ground electrode and a reference electrode. The reference was placed behind the ear upon the mastoid bone. Ideally the electrodes were all at a resistance of 10 kilo ohms (kΩ) or less with the scalp when the recording commenced.

Materials

In all trials participants were presented with a flashing disc on the screen, there was only ever a single disc present at any given time. This disc was situated just below the centre of the screen, below a small fixation cross and had a diameter of 2 centimetres (cm). During the auditory trials participants were required to listen to tones which had a frequency of 3500 Hz with each tone lasting 12 milliseconds (ms). The tactile stimulators were always set at maximum intensity. For each sound or tactile stimulus there was a total of 15 different time intervals between each tap or beep pair. These values were created by selecting a starting point of 36 ms and increasing incrementally by 12 ms until the maximum ISI of 204 ms was reached. There was a total of 150 individual tasks in each block of trials, meaning that each ISI value was presented 10 times per block of trials. White noise was presented to the participants for all of the tactile trials, this was to reduce any confounding effect from the small noise given off by the stimulator.

Design

Experiment One employed a correlational design. Two distinct correlations were investigated (with the second having 6 permutations). The first correlation looked at the relationship between the temporal window for the Flash beep task (ms) and the window for the Flash Tap task (ms).

For the second correlation the predictor variable was the peak frequencies being investigated in the visual cortex (observed across channel Oz), these were in the bands alpha (7 – 13 Hz), low beta (12 – 20 Hz) or theta (4 – 7 Hz). As such here there were a total of 6 different correlations investigated. These were the correlations between the Flash Beep window and the occipital alpha, beta and theta frequencies respectively. This is alongside the relationship between the corresponding Flash Tap window and the occipital alpha, beta and theta frequencies respectively. The predicted variable was the temporal binding window for the respective illusory task. This based upon the variation of the ISIs between each tap and beep and could theoretically be any value between 36 ms and 204 ms. The temporal window represents the time delay between double beeps or taps whereby the illusion begins to degrade. When spaced apart by more than this time period the participants begin to see one flash, when spaced apart by less they will begin to perceive a double flash.

In order to combat order effects (fatigue, practice or boredom), the order of the trials was counterbalanced. half of the participants performed the auditory trial first and the tactile trial second, whereas this order was reversed for the remaining participants.

Procedure

After being informed of their rights and accepting the conditions, participants were first asked to perform a short practice trial. This was done in order to ascertain whether they did or did not experience both the Flash Beep and the Flash Tap illusions. Participants were seated 57cm away from the computer screen and were asked to observe a series of flashing discs. They were told that there was either one or two flash and to say aloud to the experimenter how many flashes they saw. Upon hearing the participant's response (either "1" or "2"), the experimenter would press the corresponding key on the keyboard in order to advance the task. Alongside the flashes participants also experienced a double beep from the speakers or a double tap upon their left index finger. This was with the aim of producing an illusory effect and provoking the participants into saying 2, when in actual fact there was only ever 1 flash. During the Flash Tap trials participants were asked to place their stimulated hand as close to the disc, near the centre of the screen, as much as possible. During the Flash Beep trials, the speakers were placed either side of the screen, this was in order for the focal point of the sound to be roughly in the centre of the screen, again near the flashing disc. If the participant did not see the illusion they were then debriefed and asked to leave, however if they did see the illusion they were then asked to perform the full experiment.

Participants then underwent an EEG fitting, this was in order to enable the researchers to investigate alpha, beta and theta frequencies in the visual cortex during the task. Participants subsequently underwent the two trials again, this time under experimental conditions and whilst the recording took place. Once both the Flash Tap and the Flash beep trials had been completed Experiment One was finished. The participants were not de-briefed at this point as they were required to take part in Experiment Two once Experiment One was completed.

Results

Out of the 25 participants investigated, 8 participants were excluded. Three were due to poor EEG recordings and four were excluded due to their results representing extreme outliers in several respects. The final participant was excluded due to medical reasons. This bought the total sample down to 17 participants and bringing the combined sample (that is the pilot study sample combined with the experimental sample) down to 34 participants.

Before analysis could begin the temporal windows for the illusions had to be obtained. This is the spacing at which the illusion begins to degrade. This was done by fitting each individual participants' total "two" responses (always out of 10) for each ISI to a sigmoid function curve and then finding the inflection point. Upon completion these values were averaged across all participants for both the Flash Beep illusion and the Flash Tap illusion. These values can be observed below in table 1:

Table 1: The temporal windows for both the Flash Tap and the Flash beep illusion (ms)

	Flash Tap temporal window (ms)	**Flash Beep temporal window (ms)**
Mean	107.22	106.13
SD	20.35	19.49

Here we can see that the two values for the different temporal binding windows appear to be relatively similar. If we combine these values with those from the previous investigation (which utilised the same method of investigation) we can see that the two values do appear to be the same. These values can be seen in Table 2:

Table 2: The temporal windows for both the Flash Tap and the Flash beep illusion for the full sample of participants (experiment sample plus pilot sample) (ms):

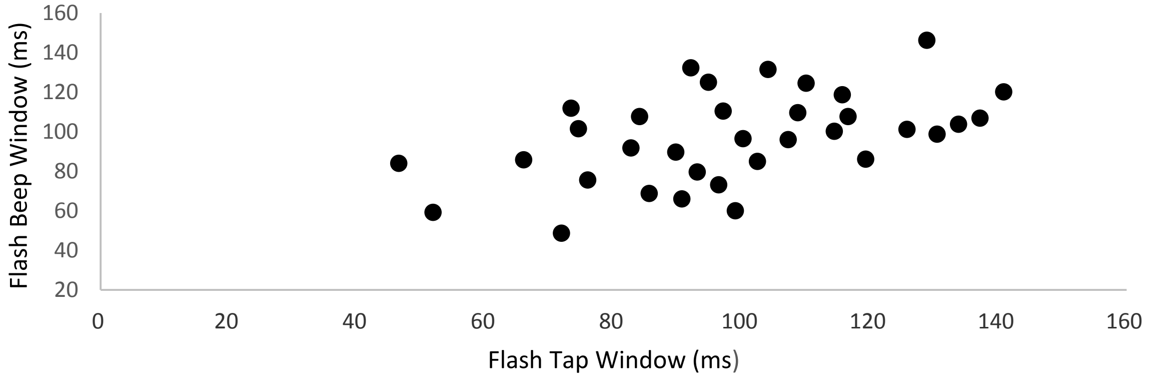
	Flash Tap temporal window full sample (ms)	Flash Beep temporal window full sample (ms)
Mean	98.85	97.13
SD	23.42	22.89

Via the use of a paired samples t-test it was confirmed that the two temporal binding windows were not significantly different from one another, t (33) = 0.43, p = .67.

Interestingly, given how the researchers were unsure of what to expect due to past discrepancies, a moderate positive correlation between these two values was observed via the use of a Pearson's r correlation investigation, this was also found to be significant: *r (15) = 0.49, p = .047*. However, when the data is combined with the data that was gathered last year the strength of the relationship remains much the same however a much higher level of significance is reached, *r (32) = 0.42, p = .003*. This suggests that there may indeed be some relationship between the two variables.

The overall correlation (for the pilot plus experimental sample) between the Flash beep and the Flash Tap windows can be observed below in Figure 1:

Figure 1: Relationship Between Flash-Beep Window and Flash Tap Window



After this it was imperative to analyse the EEG data in order to ascertain the relationship between the observed neural activity and the two illusions. This was done by performing the following process.

First the sampling rate was changed from 500 Hz to 256 Hz allowing us to investigate our data at a smaller resolution. Further to this a new reference was created, this was done by using all channels as references, if any bad channels were found they were removed and not used in this process. From this the data were segmented into 2 second chunks of data, this was taken at 2 seconds before the presentation of the first stimulus (either the first beep or the first tap). This allowed for the data to be manually assessed and any artefacts rejected depending on interference or involuntary movements (such as eye blinks or muscle twitches).

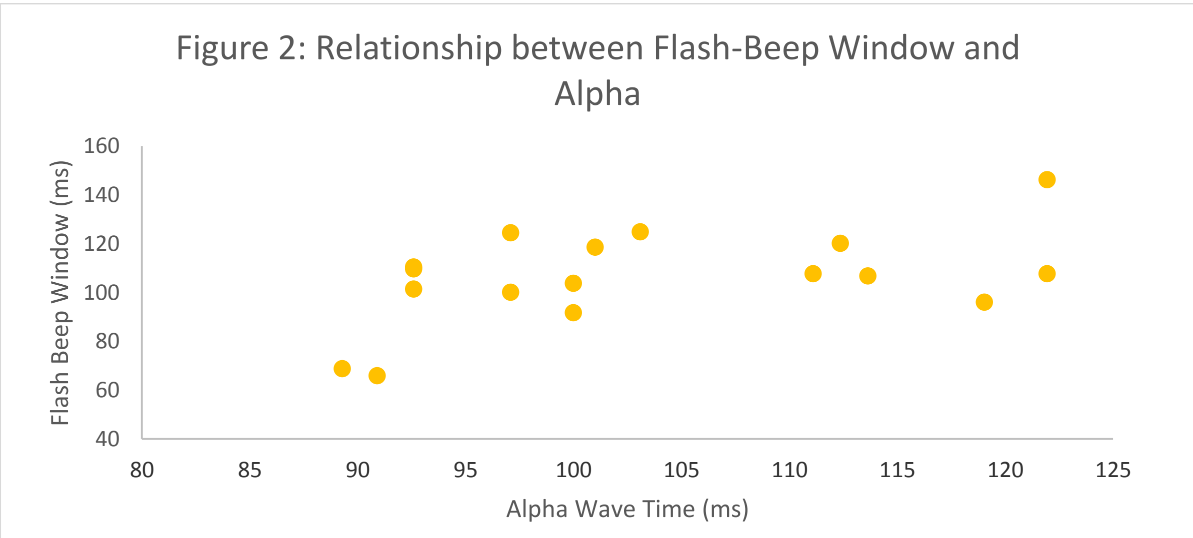
Once the data had been refined and cleaned we were able to apply Infinite Impulse Response (IIR) filters, this was in order to separate the individual wave bands in the visual cortex. For alpha a low cut off of 7 Hz was used and a high cut off of 13 Hz was used. For beta these values were 12 Hz and 20 Hz respectively, this was because we had decided to use low – mid beta for our analysis (effectively allowing us to ignoring the upper 15 Hz of the band). Finally, for theta these cut offs were set at 4 Hz and 7 Hz. A subsequent Fast Fourier Transform (FFT) was performed with a resolution of 0.1 Hz. Finally, the data for each electrode were averaged, allowing us to condense each segment into a single observable data point. This subsequently allowed us to manually investigate the visual cortex, (represented by channel Oz) for the peak alpha, beta and theta frequencies. From here each individual participant's peak frequencies were obtained and the average was found across participants, this can be observed below in table 3:

Table 3: The peak frequencies for Alpha, Beta and Theta (Hz) observed during both the Flash Tap and the Flash beep illusion.

	Tap Frequency	**Beep Frequency**
Alpha (Hz)	9.82	9.78
Beta (Hz)	14.62	14.49
Theta (Hz)	4.97	4.88

From here the relationships between the peak frequencies and the centre points were investigated. Three Pearson's r correlation tests were carried out in order to investigate the relationships between the temporal binding window for the beep illusion and the alpha, beta and theta frequencies respectively. It was found that there was no relationship between the temporal window and the peak theta frequency: $r\ (15) = -.057,\ p = .827$. The same was true for the relationship between the window and the peak beta frequency: $r\ (15) = -.280,\ p = .276$. In line with previous findings, a significant positive and moderately strong relationship was found between the temporal window and the alpha frequency: $r\ (15) = .488,\ p = .047$. This is consistent with the previous literature (Cecere, et al., 2015) and with our hypothesis.

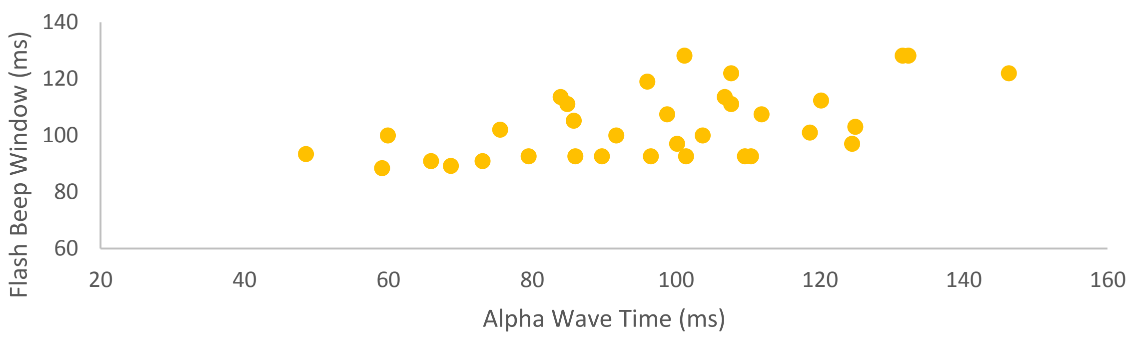
The correlation between the alpha frequency converted to a time phase and the Flash beep window can be seen below in Figure 2:



Furthermore, when this data is pooled with the data set from last year the relationship becomes even stronger and increases in significance, suggesting that this may be a strong and robust example of a relationship: *r (32) = .56, p = .001*. The relationship between the temporal binding window and beta remains non-significant: *r (32) = -.171, p = .332* as does its relationship with theta: *r (32) = .123, p = .488.* This result provides support for our hypothesis and for previous research that suggests that there is a relationship between an individual persons' peak alpha frequency and the temporal window for the Flash beep illusion.

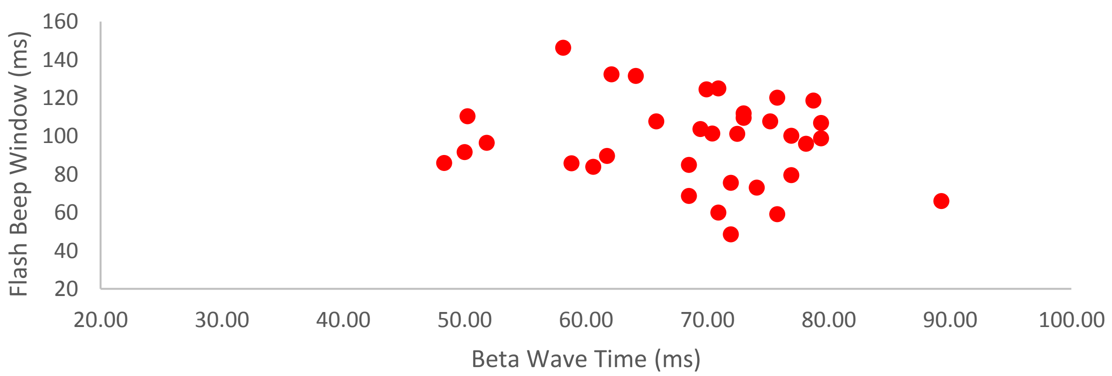
The overall correlation between the pre-stimulus alpha frequency converted to a time phase and the Flash beep window can be seen below in Figure 3:

Figure 3: Relationship between Flash Beep Window and Alpha for all participants

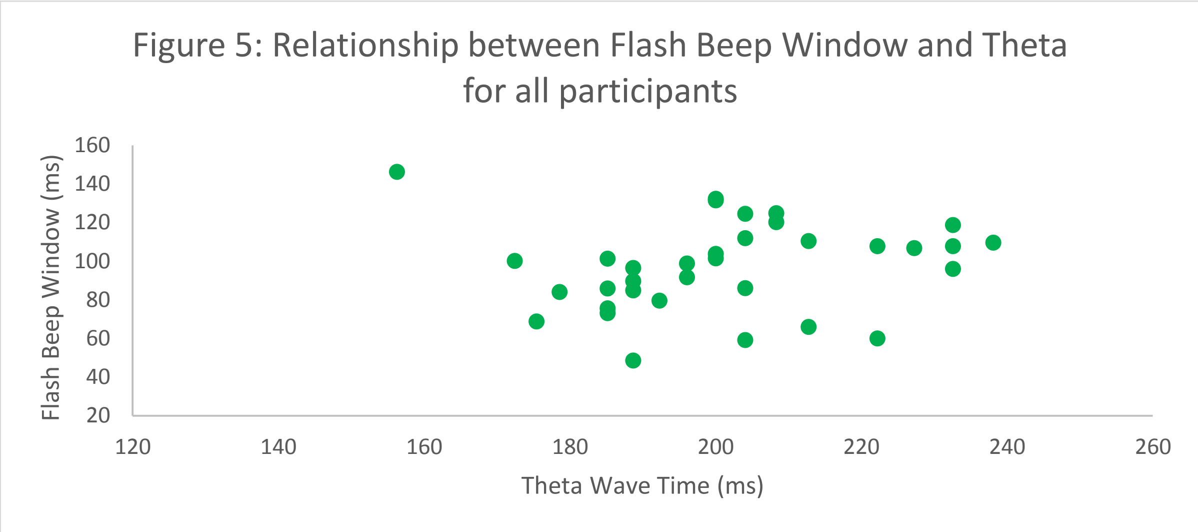


The overall correlation between the pre-stimulus beta frequency converted to a time phase and the Flash beep window can be seen below in Figure 4:

Figure 4: Relationship between Flash Beep Window and Beta for all participants.

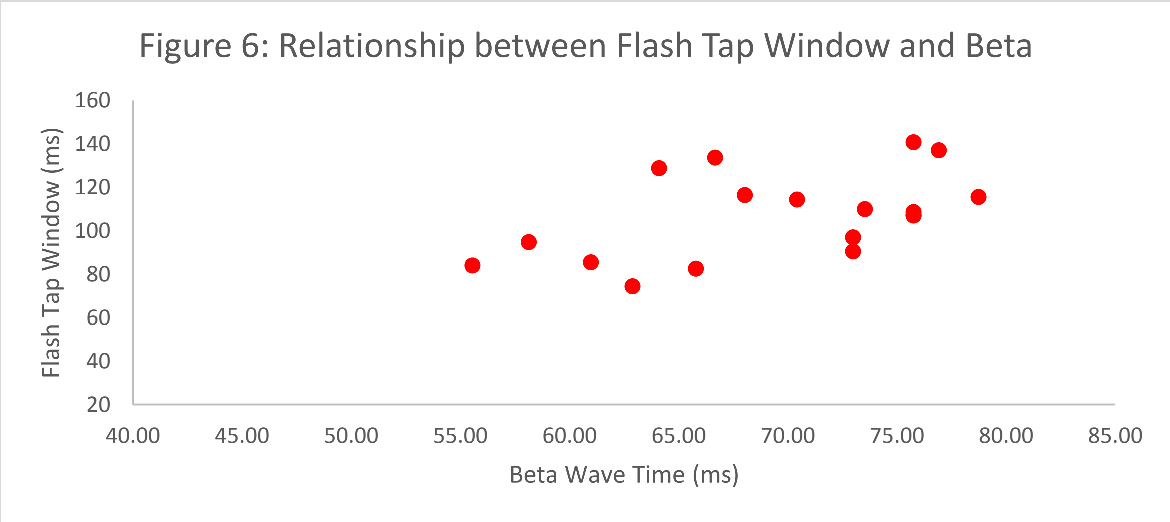


The overall correlation between the pre-stimulus theta frequency converted to a time phase and the Flash beep window can be seen below in Figure 5:



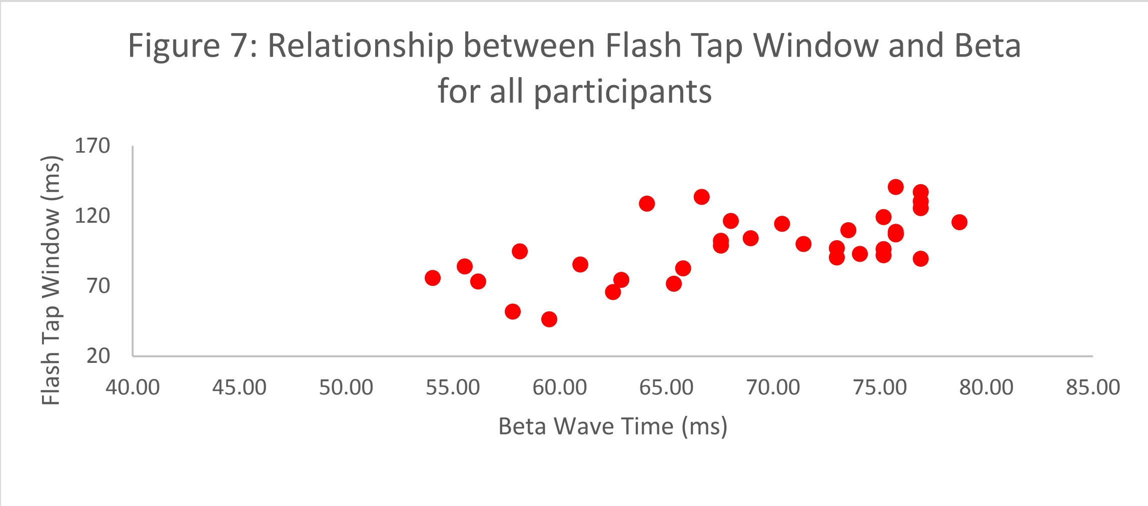
Further to this three more Pearson's r correlation tests were carried out in order to investigate the relationship between the temporal window for the Flash Tap illusion and the alpha, beta and theta frequencies respectively. It was found that there was no relationship between the window and the peak theta frequency, *r (15) = - .033, p = .900*. The same was true for the relationship between the window and the peak alpha frequency, *r (15) = - .214, p = .410*. Again a somewhat promising result was found for the beta frequency, a moderate positive relationship was found between the temporal window and the peak beta frequency and this was indeed found to be significant, *r (15) = .522, p = .032*. This was again consistent with our hypothesis.

The overall correlation between the temporal window for Flash Tap and the pre-stimulus peak beta frequency converted to a time phase can be observed below in Figure 6:

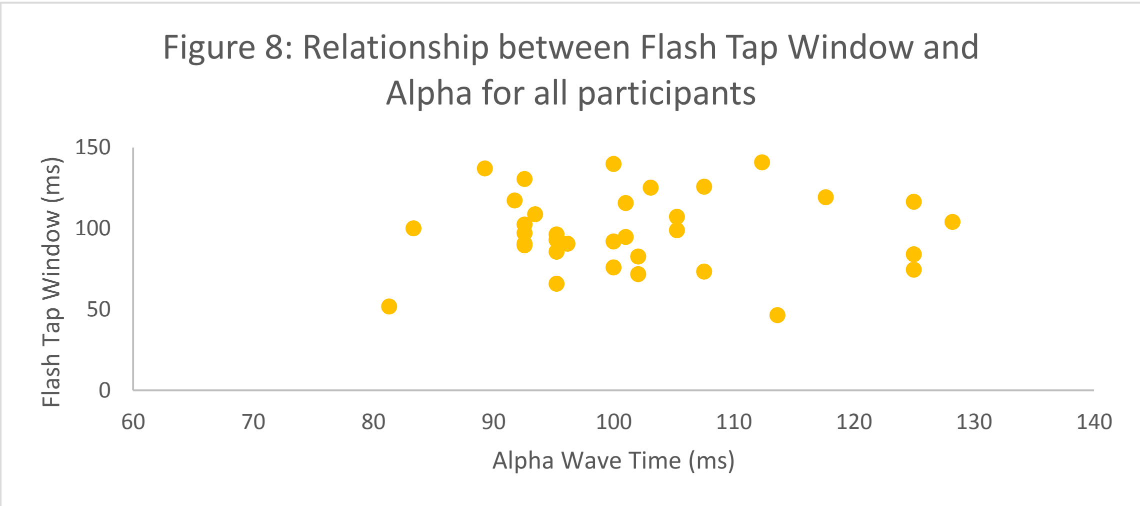


As before when pooled with last year's data the correlation increases in strength and becomes highly significant, *r (32) = .641, p < .001*, suggesting that we have found a strong and consistent relationship between the beta frequency and the temporal window for the Flash Tap illusion. As with before the correlations between the temporal binding window and the theta and alpha frequencies remained non-significant, *r (32) = .078, p = .670* for theta and *r (32) = .022, p = .901* for alpha. This result provides support for our hypothesis that suggests that there is a relationship between an individual persons' peak beta frequency and the temporal window for the Flash Tap illusion. We have also successfully replicated both results from the literature and the interesting results that we found the previous year, these findings also provide us with a justification for Experiment Two, enabling us to go ahead with the second investigation.

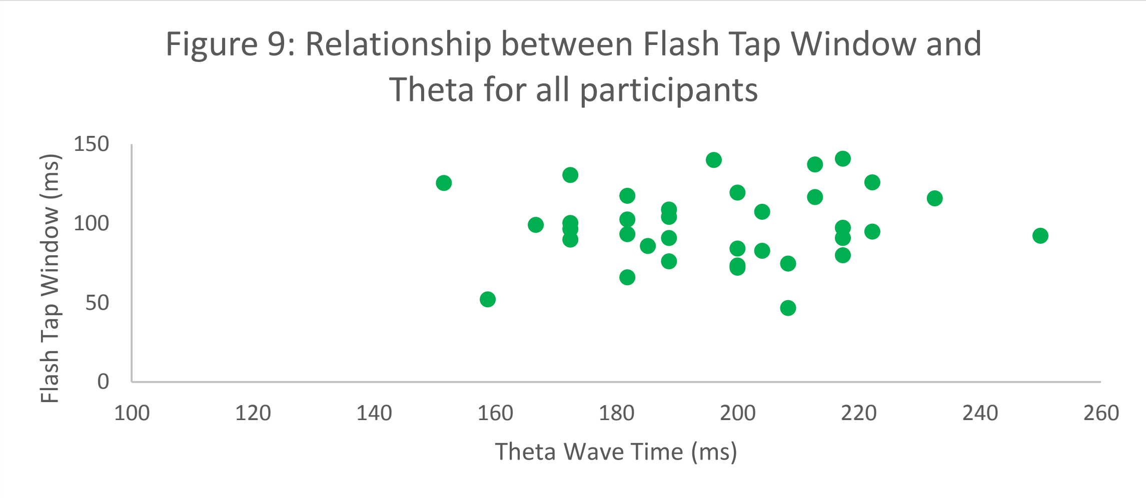
The overall correlation between the temporal window for Flash Tap and the pre-stimulus peak beta frequency converted to a time phase can be observed below in Figure 7:



The overall correlation between the temporal window for Flash Tap and the pre-stimulus peak alpha frequency converted to a time phase can be observed below in Figure 8:



The overall correlation between the temporal window for Flash Tap and the pre-stimulus peak theta frequency converted to a time phase can be observed below in Figure 9:



Experiment Two

Methods

Participants

In Experiment Two there were a total of 17 participants, who were recruited via a volunteer system and were all students studying at the University of Essex. These were all participants who had taken part in Experiment One, and as a result the researchers already knew that they experienced the illusion consistently. The age range was 18-24 (median: 21) and the sample included a mixture of males (5) and females (12). Sixteen right handed individuals and 1 left handed individual was used. As they had taken part in Experiment One participants were known to have no known confounding impairments. For this part of the study participants were required to fill in a pre-screening form to ensure that none of them were suffering from any neurological or psychological impairment, or were using any medication or substances that may have contraindicated with the TMS, as such much care was taken to prevent any harm being caused to the participant.

Apparatus

As in Experiment One the participants were presented the visual flash stimuli via the Dell Optiplex 960 computer on the same Viewsonic graphics series G90fB CRT monitor with the same specifications as in Experiment One. For the presentation of the auditory stimulus and the white noise the Nicole flat USB speakers were again placed either side of the monitor. For the presentation of the tactile stimulus the Heijo Research Electronics tactile stimulator was placed upon the left index finger or the right index finger of the participant, this was dependent on the condition currently being experienced by the participant. Again the presentation of the stimulus was done via E-Prime (2.0), the programmes used for the recording and analysis of the EEG data was the same as before (Brain Vision Recorder and Brain Vision Analyser [2.0] respectively). The same 64 channels were used for this investigation as the last, alongside a ground electrode and a reference electrode, once again placed upon the mastoid bone, all with an ideal resistance of 10kΩ or less.

Participants underwent a 15 minute TMS protocol, this was programmed using E-prime (2.0) and was administered via a Magstim BiStim^2 stimulation device working alongside a Magstim 200^2 stimulation device, the device was always set at an intensity of 70%. Coils were placed over the visual cortex (on electrode Oz) and on the somatosensory cortex (on electrode C4). The directionality of the protocol was determined by the timing of the magnetic pulse, coil C4 always pulsed first followed by coil Oz, the timing between the two coils was determined by each individual participant's individual beta peak frequency in the visual cortex (across channel Oz). This was calculated via an excel spreadsheet and represented the peak frequency minus 3 Hz converted to a time phase (done via the following equation: $t = 1000/ (f – 3)$, this resulted in an average time delay of 88.7 ms between the first and the second pulse.

Materials

As before participants were presented with a single flashing disc situated just below the centre of the screen, this had the same properties and was placed in exactly the same place on the screen as in Experiment One. Unlike the previous experiment there was no auditory stimulus, only tactile stimulation experienced upon the index finger. For both the right hand and left hand stimulation there were a total of 15 different time intervals between each pair of taps. As before there was a total of 150 individual tasks in each block of trials, meaning that each ISI value (again 36 ms – 204 ms) was presented 10 times per block of trials. Again white noise was presented to the participants for all trials in order to drown out any potential confounding noise given off by the tapper.

Design

Experiment two utilised a 2 x 2 fully within-subjects design. The first independent variable was the finger upon which the tactile stimulator was placed (either the right index finger, or the left index finger) each participant underwent a left hand trial and a right hand trial. The second independent variable was the TMS condition, participants completed each task once before they underwent the TMS protocol and then once more 20 minutes after the protocol had finished.

There were two dependent variables in Experiment Two, the first being each individual's peak beta frequency (7 – 20 Hz) across their visual cortex. And the second being the temporal window (corresponding to the spacing where each participant's individual illusory effect begins to degrade). As before this could be any value between 36 ms and 204 ms. In order to combat order effects, fatigue, practice or boredom, the order of the trials was again counterbalanced. Half of the participants completed the right hand trial first, and the other half completed the left hand trial first.

Procedure

Participants were first required to perform two Flash Tap trials, as before they were seated 57cm away and asked to count the number of flashes on the computer screen. Again saying each value aloud in order for the researcher to input the response on the keyboard. Alongside these Flash Tap trials participants underwent a full EEG scan in order to assess neural oscillations (most importantly beta frequencies) in the visual cortex. One Flash Tap trial required the participant to wear the tactile stimulator upon their right index finger, whereas the other required their left index finger.

Once complete the participants then underwent a TMS protocol in order to modulate the connection between the tactile area of the brain and the visual cortex. This was done by first obtaining the value of the peak beta frequency of the individual participant (this was done by following the same procedure as the analysis of the EEG data for the results of Experiment One). Once this frequency was observed 3Hz was subtracted from it. Finally, this frequency value was converted to a time which corresponded to the spacing of the two magnetic pulses across the scalp. This was done in order to entrain neural activity in an attempt to reduce the peak frequency of any travelling wave across the two areas of the brain being investigated (in this case the visual cortex and the somatosensory cortex).

The TMS protocol took 15 minutes and once completed participants were then asked to wait for a further 20 minutes. This was to give the processes associated with the CCPAS protocol time to complete, it also acted as a way for the participant to have a break in order to reduce fatigue effects for the final part of Experiment Two. Once this wait period was over the participants again had to complete the Flash Tap tasks, again one on the right hand and one on the left hand. Once this had been completed the participants were debriefed and Experiment Two was completed.

Results

All participants who took part in Experiment One also took part in Experiment Two as a result there were no exclusions leaving us with the full sample of 17 participants.

For our first investigation we wanted to look at handedness in terms of the illusion, this is essentially whether there is any significant difference between the two Flash Tap windows for the right hand and for the left hand. As in Experiment One the temporal binding windows for each condition was again found by investigating the responses of the participants in the form of a sigmoid function curve. The average temporal window for the two hands can be observed below in Table 4:

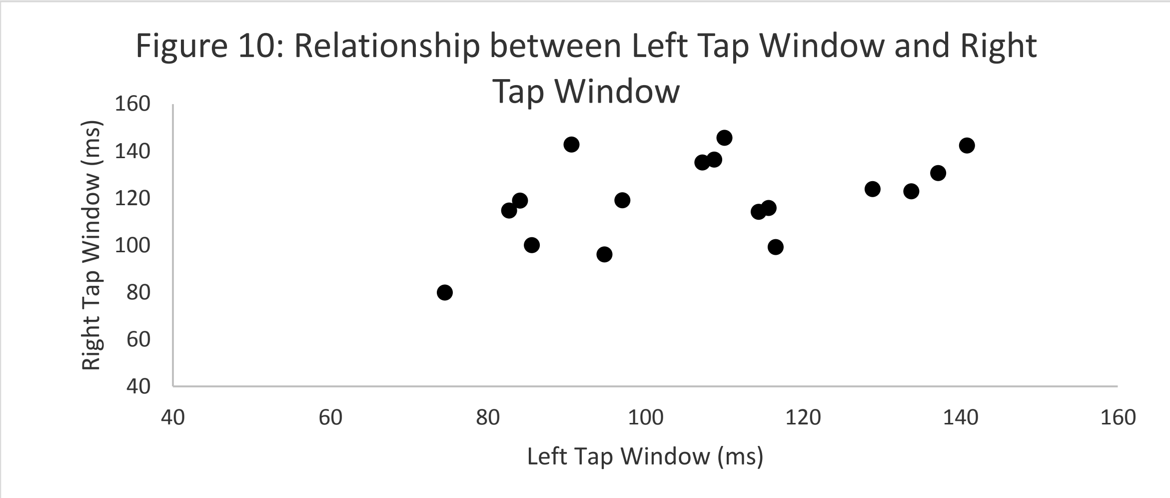
Table 4: The temporal windows for both Flash Tap on the left hand and Flash Tap on the right hand (ms)

	Left Tap temporal window (ms)	**Right Tap temporal window (ms)**
Mean	107.22	119.88
SD	20.35	18.38

A subsequent paired samples t-test was performed in order to investigate the difference between the hands. It was found that the right tap window was significantly wider than the corresponding left hand window, *t (16) = -2.64, p = .018*. This is not entirely what was expected but it does appear that the hand upon which the tactile stimulator is placed does indeed make a difference to the illusory effect.

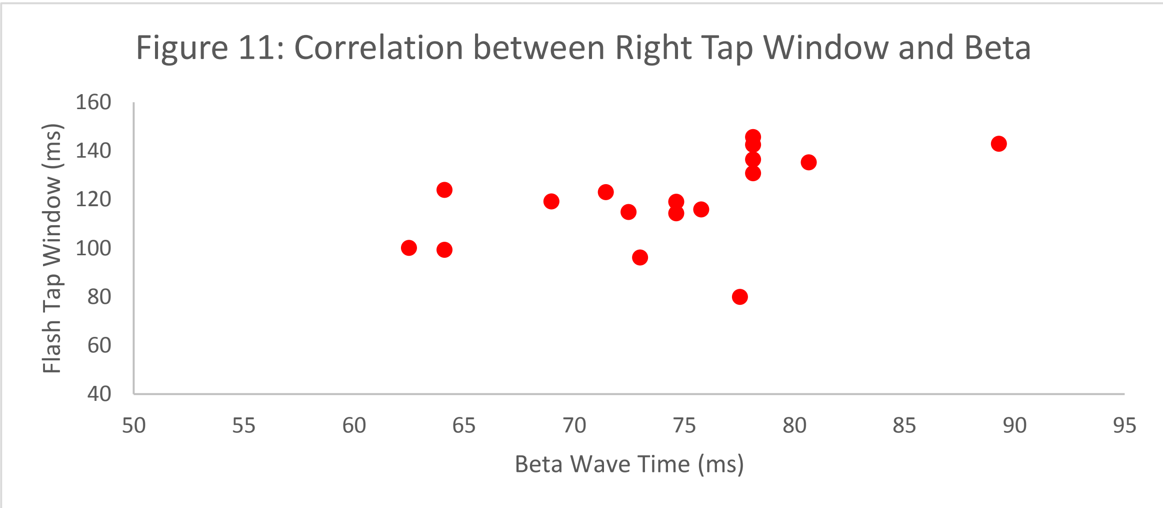
A Pearson's r correlation was however carried out in order to assess the relationship between the temporal window of the two hands. A moderate relationship was indeed found and it was in fact significant*, r (15) = .482, p = .05*. This would suggest that despite the difference in the temporal binding windows the illusory effects for the right and the left hands are still related to one another, which is what we should expect.

The correlation between the tap window for the right hand and the tap window for the left hand can be observed below in Table 10:



Further to this another Pearson's r correlation investigation was carried out in order to see whether the same relation between beta and the temporal window as was found for the left hand could again be found for the right hand. This investigation suggested that there was also a moderately strong significant correlation between the right temporal window and the peak beta frequency as was found for the left hand, *r (15) = .522, p = .032*.

The correlation between the tap window for the right hand and the pre-stimulus peak beta frequency converted to a time phase can be observed below in Figure 11:



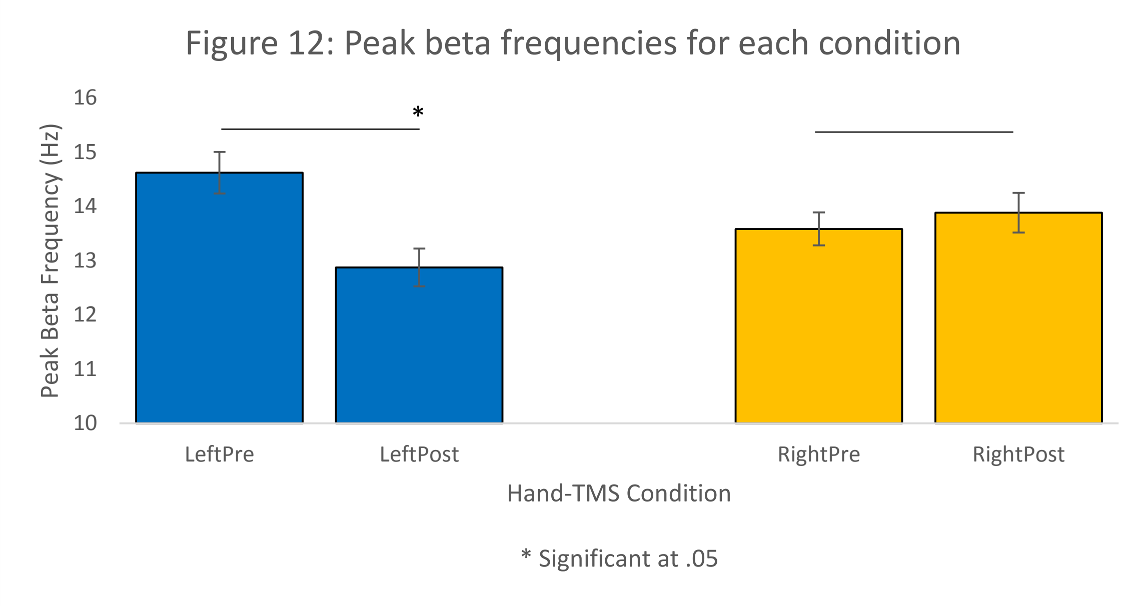
Before analysis into any difference in Flash Tap window it was imperative to first find out whether our stimulation was successful in changing the beta frequency within the visual cortex. As before this was done by changing the sampling rate from 500 Hz to 256 Hz, and then setting a new reference with all of the channels acting as references, taking care to remove any bad channels. From this the data were segmented, at every 2 seconds before the presentation of the first tap. This allowed for the data to be manually assessed and any artefacts indicating interference or involuntary movements were rejected. From here IIR filters were applied, with a low cut off set at 13Hz and the high set at 20Hz in order to isolate the peak beta frequency for the low to mid range. An FFT was performed again with a resolution of 0.1Hz. Finally, the data was averaged, allowing the visual cortex, channel Oz to be manually investigated for the peak beta frequency. From here each individual's peak frequencies were obtained and the average was found across participants.

Once we had found the individual beta peaks for all participants we were able to average this to find average peaks for all four conditions, these data can be observed below in table 5:

Table 5: Average beta peaks pre and post-stimulation:

	Beta Left Pre-TMS (Hz)	**Beta Left Post-TMS (Hz)**	**Beta Right Pre-TMS (Hz)**	**Beta Right Post-TMS (Hz)**
Mean	14.62	12.87	13.58	13.88
SD	1.42	1.44	1.25	1.50

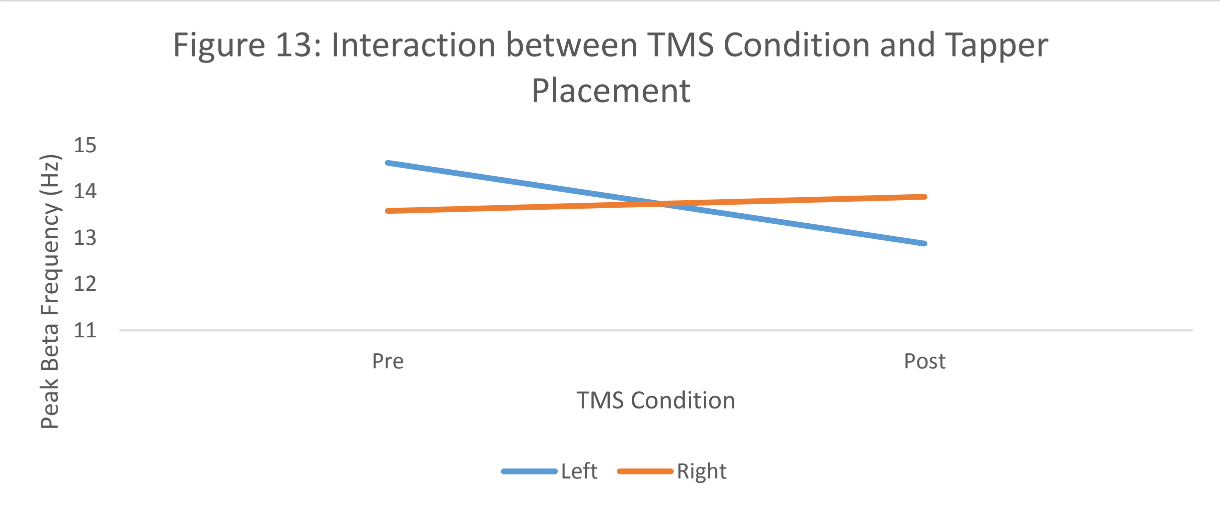
The difference between peak beta frequencies for all conditions can be observed below in figure 12:



A fully within-subjects' ANOVA was conducted in order to test the interaction between the effect of TMS and the hand the tapper was placed upon on the peak beta frequency, this indicated a significant interaction between the two conditions, *F (1, 64) = 8.50, mse = 2.10, p = .005*. Planned comparisons were then performed in order to investigate any difference in the beta peaks, this was done via a series of paired t-tests. Given that 4 tests were planned a Bonferroni adjustment was performed which resulted in a significance level of 0.0125 being desired.

It was found that the peak beta frequency prior to TMS was higher than the peak after TMS for the left hand, this was still significant despite the higher level of stringency, *t (16) = 4.23, p = .001*. It was also found that the peak beta frequency prior to TMS was lower than that after TMS for the right hand, however this was not found to be significant, *t (16) = -1.42, p = .175*. This suggests that there was a difference in peak beta frequency before and after TMS, but only for the left hand. Given that we were stimulating the somatosensory cortex in the right hemisphere this was the expected result and suggests our stimulation was successful. A paired t-test was also carried out in order to investigate the difference between the beta values for the left hand and the right hand trials prior to TMS stimulation, this was to make sure that we were investigating similar values. The result of this was that the beta peak frequency for the left hand was lower than that for the right hand, however due to our high level of stringency we are unable to accept this as being significant, *t (16) = 2.79, p = .013.* We also used a paired t-test to investigate whether there was any difference between the left hand and right hand beta peak post-TMS. We would expect this to be significantly different. Unfortunately, whilst the left hand beta peak was found to be lower than that of the right hand this was not quite significant due to our high level of stringency, *t (16) = -2.69, p = .016.*

The interaction between the TMS condition and the tapper hand placement for the peak beta frequency can be seen below in Figure 13:



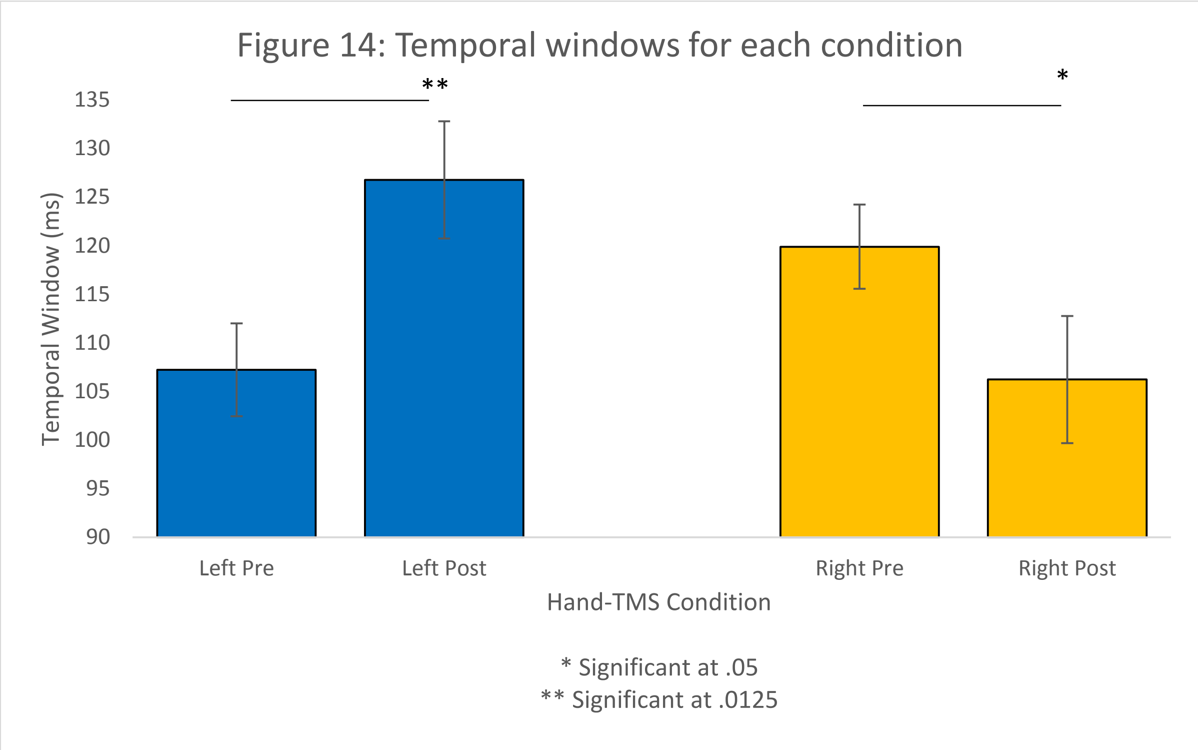
As with Experiment One in order for us to analyse our behavioural data the temporal window for each participant had to be investigated, this was again done by fitting the data to a sigmoid function and then observing the inflection point. This was done for all four conditions and c an be observed below in table 6:

Table 6: The mean temporal windows for each hand pre- and post-stimulation:

	Left Pre TMS (ms)	**Left Post TMS (ms)**	**Right Pre TMS (ms)**	**Right Post TMS (ms)**
Mean	107.22	126.77	119.88	106.22
SD	20.35	25.59	18.38	27.82

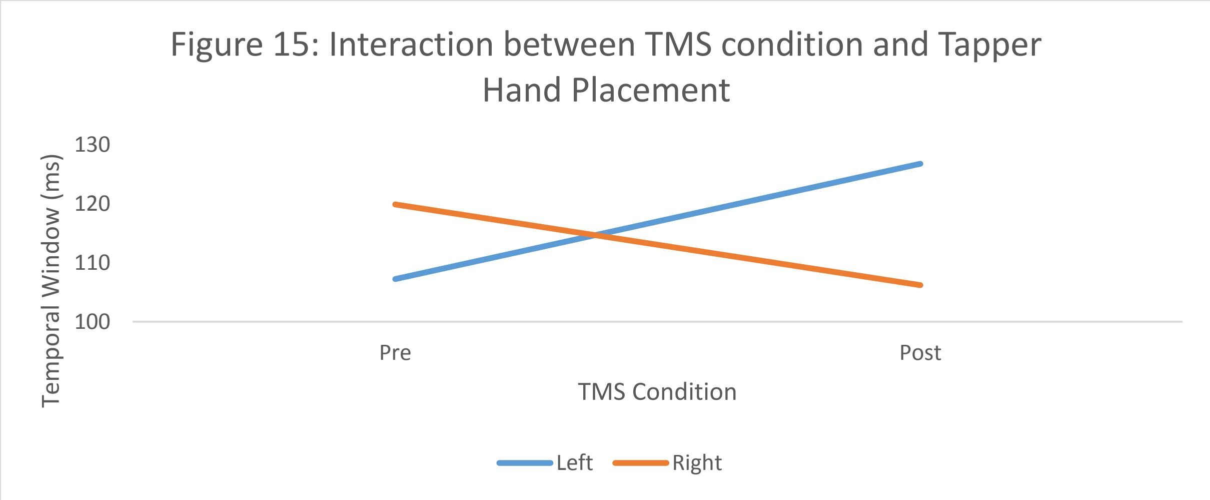
It can be seen that there does appear to be a difference between the Pre and Post stimulus conditions for the left hand predominantly. There is also some variation between the other conditions.

The difference between the temporal windows for all conditions can be seen below in figure 14:



As before a fully within-subjects' ANOVA was conducted in order to test the interaction between the effect of TMS and the hand the tapper was placed upon on the temporal window, again this indicated a significant interaction between the two conditions, *F (1, 64) = 8.59, mse = 545.33, p = .005*.

The interaction between the TMS condition and the tapper hand placement for the temporal window can be seen below in Figure 15:

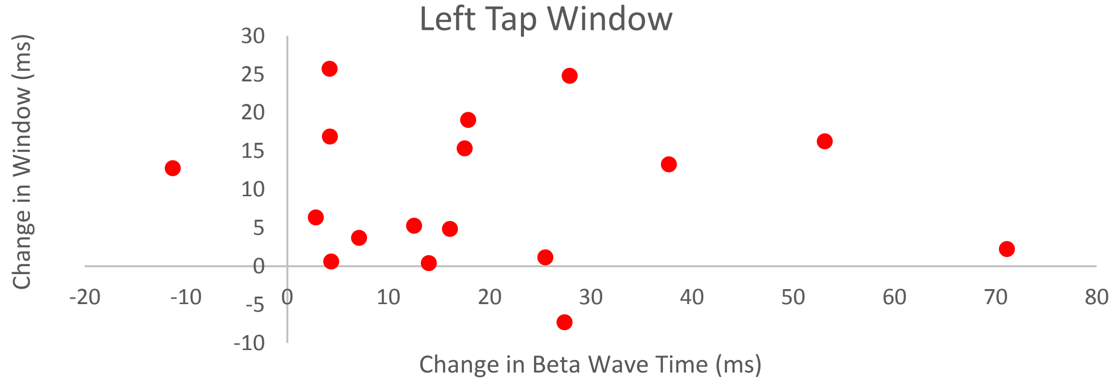


Planned comparisons were then performed in order to investigate any difference in the beta peaks, this was again done via a series of paired t-tests. As before a significance level of 0.0125 was accepted due to the four planned comparisons being carried out. It was found that the window prior to TMS was significantly smaller than the window after TMS for the left hand, this held firm even after the Bonferroni correction: *t (16) = -4.01, p = .001*. Whilst the temporal window for the right hand was found to be larger prior to the TMS this was not found to be significant: *t (16) = 1.83, p = .086.* This is consistent with our hypothesis and suggests that there may be a causal relationship between an individual persons' peak beta frequency and their temporal window for the Flash Tap illusion. Another paired samples t-test was carried out in order to investigate whether the tap window was different for the left and the right hand prior to the TMS stimulation. It was found that the left window was smaller than the right window, and this difference was found to be significant at 0.05. However due to the higher level of stringency we are unable to accept this difference as significant: *t (16) = -2.639, p = .018.* Again as before a somewhat disappointing result was gained from the final paired t-test that was carried out in order to investigate the difference between the left and right window post-TMS, here we should expect the left window to be significantly wider than the right. Whilst the window for the left hand was found to be significantly larger than the window for the right hand post-TMS at 0.05, this was not found to be significant at the higher level of stringency that was utilised in this investigation: *t (16) = 2.66, p = .017*.

The final analysis that was carried out was to assess the correlation between the degree of change in peak beta frequency and the degree of change for the temporal window exclusively for the left hand. A Pearson's r correlation was carried out in order to test this relationship. Unfortunately, no relationship was found between the two values directly, *r (16) = -.09, p = .73.* This finding is unfortunate as it suggests that there is no direct linear correlation between the change in the beta peak frequency and the change in temporal window for the left hand. This makes it difficult to explain the changes to the temporal window that have been presented in this investigation.

The interaction between the TMS condition and the tapper hand placement for the temporal window can be seen below in Figure 16:

Figure 16: Correlation between Change in Beta and Change in Left Tap Window



Discussion

This research predominantly began with the aim of producing a comprehensive investigation of many of the properties of the Flash Tap illusion first investigated by Violentyev et al., (2005), whilst also looking to corroborate some previous investigations of the Flash Beep illusion (Shams et al., 2002; Romei et al., 2012; Cecere et al., 2015; Cooke et al., In preparation). Overall the findings of this investigation could be said to be positive, although there were also a few slight inconsistencies compared to what was expected. The findings, inconsistencies and subsequent implications of these will now be discussed.

In the first instance what we originally set out to investigate were the two illusions in relation to each other; in other words, we asked the question is there a significant correlation between the temporal binding window for the Flash Tap illusion and the corresponding window for the Flash Beep illusion? Essentially the researchers did not know what to expect here as previous research had been incredibly mixed, with a significant correlation found on one occasion, and no correlation found on another (Cooke et al., In preparation). In this case a significant correlation of moderate strength was found between the two windows (r = .49). Even more striking, when combined with the data from last year (which using the same protocol found a slightly weaker relationship that did not quite reach significance) the strength of the correlation remains much the same (r = .42) but the level of significance increases greatly. This would seem to suggest that the two windows are indeed related in some way. However, this is far from a robust relationship, given the inconsistencies we have found in past investigations. Obviously this potential relation still requires further investigation in order for us to comprehensively claim the two are indeed related.

Secondly we looked to investigate any correlation between the two windows and one of three occipital neural oscillatory processes (i.e. Alpha, Beta, Theta). Given past research by Romei et al., (2012), Cecere et al., (2015) and Cooke et al., (In preparation) we should expect to find a significant correlation between the peak occipital alpha frequency and the size of the temporal window exclusively for the Flash Beep window, this relationship should be moderately strong, no other relationships should be found. This is in fact exactly what was found (r = .49), suggesting that this relationship is indeed largely robust. As before when combined with last year’s data the significance and strength of the relationship increased greatly (r = .56) with the other two relationships remaining unchanged.

We also looked to investigate the potential relationship between the peak occipital beta frequency and the temporal binding window exclusively for the Flash Tap illusion. This was a rather surprising finding from research conducted last year (Cooke et al., In preparation), hence why the researchers were re-investigating in order to corroborate this relationship. As before we also expected to find no evidence of any other relationship between this window and the two other frequencies being investigated. As before a significant relationship between the beta frequency and the temporal window was found (r = .52), again when combined with last year's results the strength and the significance of the relationship was striking (r = .64). No other relationships were found regardless of whether any data was combined. These results were exactly as hypothesised, and as they provided supported for the hypothesis it provided justification for to carry on with the investigation into the relationship between the beta frequency and the Flash Tap window.

Experiment Two set out to further investigate this relationship and also to provide some more of an insight into the properties of the Flash Tap illusion. Here the researchers set out to investigate whether handedness influences the illusion. The question was asked, does placing the tactile stimulator on the left hand provoke a different illusory response from the participant compared to when the stimulator is placed on the right hand? We first set out by investigating whether there was any significant difference between the temporal windows for the left hand and for the right hand for the Flash Tap illusion. We would expect there to be no real difference as the illusory process taking place should remain the same. However, what we found was the opposite, the right hand window appeared to be significantly larger than the window for the left hand. It is not known exactly why this is the case, but mere speculation may suggest that the increased sensitivity of the right hand (as many subjects were right handed) may have meant that when this hand is used the sensitivity is more likely to induce an illusory effect, this possibility will be discussed in more detail later on. Regardless of this, a further investigation found the two temporal windows to be significantly related, suggesting that they two windows may be different but they are still connected to one another in some way (r = .48).

From here we looked to apply the CCPAS protocol to the right hemisphere in order to produce a significant reduction in peak occipital beta frequency for the left hand only. As such we investigated the beta frequency Pre- and Post-CCPAS and crucially found a significant reduction in peak beta frequency after the TMS protocol took place. No significant change in beta frequency was found during the right hand task, which was again expected. Further to this we again investigated Pre- and Post-TMS in order to ascertain whether we had produced a significant change in behaviour, in other words we wanted to see whether the temporal window was significantly wider for the left hand Post-TMS condition compared to the Pre-TMS condition. Interestingly this is indeed what we uncovered and again there was no significant change in the right hand window (although there did seem to be a reduction, this was not quite significant but nonetheless raises a few questions that will be discussed at a later point in this report). Finally, we looked to investigate the overall coherence of the two changing values, that is whether the change in beta correlated to the change in behaviour. Unfortunately, this was not the case, with the correlation being very far away from reaching significance, again raising a few questions as this suggests that the change in beta has no direct bearing on the magnitude of the change in behaviour. Further possibilities as to why this was found will be discussed later in the report.

Overall however it is safe to say that the findings of this investigation are on the whole positive. We managed to, yet again, reconfirm the findings of Romei et al. (2012), Cecere et al. (2015) and Cooke et al. (In preparation) and replicate the correlation between alpha and the Beep window. We also provided support for our own hypothesis, that of the relationship between occipital beta and the Tap window. We also provided an interesting insight into how handedness makes a difference to the illusion. Finally, we were able to tentatively suggest a potential causal relationship between occipital beta and the Flash Tap binding window, however the exact details of this are a little sketchy and hence further work on this subject is absolutely necessary in order for us to conclude that the relationship is of a causal nature.

In terms of improving upon the design that was used in this instance, it is imperative that the next set of investigations look to include a number of control conditions in order to protect against any potential confounds. As a result of the lack of control it is as yet difficult to conclude that the change in beta frequency that was induced by the stimulation was directly responsible for the change in temporal window, more so with the lack of apparent coherence between the two changes. Albeit arguably unlikely it may have also simply been bought about by the simple act of the TMS. When participants undergo a novel technique such as this their state of mind can often become altered, for example by stress or anxiety, this can also influence the behaviour of the participants as well as any potential experimental effect. Less likely (but again entirely possible) is the idea of demand characteristics, whereby participants change their responses autonomically based on the desires (or perceived desires) of the experimenter. This is however unlikely as the participants were all unaware of the illusory effect and great care was taken to avoid any suggestion of an illusion reaching the participant. Furthermore, the stimulation took place upon the right hemisphere, meaning that we always expected a change to the left hand. Given that the vast majority of the participants that were tested were not psychology students we should perhaps expect them to not have a large knowledge of the contralateral nature of the brain. As a result of this if our study did fall victim to any demand characteristics we could perhaps expect to see a change for the right hand but not the left, which is clearly not the case. Regardless of this it is still a possible confound to our findings and further work should attempt to remove even the slightest possibility of this occurring.

As such including a number of control conditions would look to allay these fears and provide more comprehensive evidence as to the change in behaviour being as a direct result of the change in beta. In terms of the CCPAS protocol this could be done via several methods, for example a simple sham stimulation could be used, this would induce the same conditions of completing the TMS without any of the experimental effects. We could also look to reverse the directionality of the stimulation, that is instead of stimulating from electrode C4 to Oz we could stimulate Oz first and then C4, this should also not change the behaviour if our hypothesis is correct. On a similar train of thought it would perhaps be somewhat beneficial to include a control "double flash". If occasionally there was in fact two flashes, as opposed to always being one, this could perhaps induce a stronger effect. If any bias did take place it could be simply as a result of the participant working out the aims of the study, this could be by working out, or even guessing that there is only ever one flash.

However, it would be less likely for a participant to assume that there is only one flash if in fact there was not only one flash but occasionally two to, this would act to reinforce the belief that they are attempting to distinguish between one and two flashes.

Another potential addition to the investigation would look to confirm the changes that took place as the result of the CCPAS. As stated earlier the idea of using CCPAS in this particular method of investigation was something of a risk, as such it would have been disappointing, yet entirely possible that no change took place as a result of this method. Thankfully changes did take place, which suggests the method we used is able to modulate a connection between two interconnected areas of the brain, in this case based exclusively on the properties of a proposed travelling wave between them. As such in order to provide further robustness towards the effect we could also look to modulate the alpha wave. We could hence look to replicate Romei et al., (2012) and Cecere et al., (2015) who demonstrated the relationship that exists between the peak alpha frequency and the Flash Beep illusion. We could then attempt to use the CCPAS between the auditory and visual cortex, and again base the spacing on each person's individual alpha frequency (perhaps again minus 3 Hz), with the aim of modulating the alpha wave and subsequently modulating the temporal window for the illusion. This would be beneficial in one of two ways, first it would look to replicate the causal relationship between the alpha frequency and the temporal window for the Flash Beep illusion, given how recent the suggestion of a causal relationship between the two is, any replication should be welcomed. Secondly it would look to replicate our findings in regards to the CCPAS protocol with a relationship that has already been put forward in the literature. This however may be slightly problematic as using TMS on the auditory cortex is often notoriously difficult, this is because of the large number of muscles and nerves that exist around and above the ear, with area close to the auditory cortex. This can induce painful or uncomfortable involuntary muscle twitches along this area, these may distract or cause discomfort to the participant potentially to the point of withdrawal.

On a similar topic, one way in which we could more reliably replicate the causal nature of the relationship between beta and the Flash Tap window is to perhaps use tACS to modulate the relationship, rather than CCPAS. Unlike the CCPAS method tACS has been used in order to modulate neuro-oscillations in this manner before. The most obvious example of this comes from Cecere et al., (2015) who used this method as a way of entraining alpha waves in order to modulate the temporal window for the Flash Beep illusion. If we were to replicate our current study it would be beneficial to utilise tACS for two reasons. Firstly, it is a more established technique and as a result it is possible that this would make it more likely to yield results compared to the experimental CCPAS method. As a result, if we were able to replicate the causal relationship between the beta frequency and the Flash Tap window by using this method we would once more provide evidence for our hypothesis. Secondly, if we were to find similar results it would provide further support for us using CCPAS in the manner that we did, again providing confirmation of the properties of the novel method of neurostimulation.

Regardless of where we could apply improvements to our methods, generally the findings overall were somewhat supportive of our original hypothesis. Crucially we found that there does appear to be a relationship between occipital beta and the Flash Tap window, but this begs the question as to why this could be the case. One potential explanation for this is that the visual system (and potentially other multisensory systems) decode information differently depending on what this information is. As such when the visual cortex looks to integrate vision with sound it performs this task differently to when in integrates vision with touch. This may appear somewhat speculative, but examples linking auditory tasks with the alpha frequency have already been highlighted earlier in this report (for example Müller et al., 2013). These researchers demonstrated that by playing pieces of music to participants they could produce alpha responses in the auditory cortex. Furthermore, they were able to produce similar responses even when replacing short sections of the music with white noise (creating an illusory percept of music at the same time).

Alongside this research has also found that abnormal hearing (such as with the condition Tinnitus) can be linked to abnormal alpha (Schlee et al., 2014) or abnormal tau responses in the auditory cortex (Dohrmann, Elbert, Schlee & Weisz, 2007; Dohrmann, Weisz, Schlee, Hartman & Elbert, 2007; Fulioka, Mourad & Trainor, 2011). The tau wave tends to cover the range of frequencies between 8 – 12 Hz, with the average being 10 Hz. This is the average frequency of the alpha band across the visual cortex when the Flash Beep task is taking place, the same frequency that correlates strongly with the temporal window for this illusion.

Further to this idea research continues to link beta frequencies across the motor cortex, with tasks that require tactile information or motor control (Cassim, 2001; Paus, Siplia & Strafella, 2001; Rubino, Foffani, et al., 2005; Robbins & Hatsopoulos, 2006; Baker, 2007). Engel and Fries (2010) even stated in fact, that beta oscillations in the motor cortex are critical to maintaining regular functions of the motor and tactile systems. As such, given these two pieces of information if this hypothesis were to be correct, we should expect to see a correlation between certain aspects of an auditory-visual task and the tau wave (or in this case alpha wave), which is what we have found. Likewise, we should also expect to see a correlation between certain aspects of a visuo-tactile task and the beta frequency, much like what has been observed. Of course this is a mere hypothesis, but nonetheless requires further investigations in order to fully understand the principles behind this causal relationship.

Alongside these potentially explainable phenomena there are also some parts of our work that is not so easily explainable. Firstly, one issue is the fact that the CCPAS protocol did not affect all people, that is we did not always see a decrease in each person's individual beta frequency. This suggests that our method of investigation was not as reliable as it could be. One potential explanation for this could be variations in skull thickness. Skull thickness tends to deviate slightly from person to person and even across genders, with the average thickness of the male skull being around 6.5 mm, with the female skull being on average around 0.6 mm thicker (Li, Ruan, Xie, Wang & Liu, 2007). These variations in skull thickness may have gone some way to produce some kind of interference with the TMS. Essentially this would mean that as we had the intensity of the magnetic pulses always set at 70% it is possible that for some people to receive a strong enough stimulation (perhaps even to reach a threshold) we would have to set it higher. There is indeed evidence in the literature to suggest that some techniques used to measure and investigate brain activity are affected by individual skull and scalp thickness (Cuffin, 1993) and there is also a natural variation in TMS effectivity within the general population (Wasserman, 2002). As such, one potential solution would be measuring skull and scalp thickness using the non-invasive techniques put forward by Li et al., (2007) and using a variable intensity level based on this information. Failing that simply setting the intensity level higher on all trials may increase our likelihood of having an effect of TMS even among those with thicker skulls. It must be stated however that this method is not without its risks, it would inadvertently increase the risk of adverse effects brought on by the TMS protocol itself. As such we would have to decide whether the increased risk to the participants' health would be worth the potential increase in the reliability of the method and the overall strength of our findings.

Along a similar line of reasoning is the fact that many of our participants did not see the illusion reliably. As such out of 67 participants 42 were excluded from the full study and only 25 managed to reliably see the illusion. Even then a small proportion of these 25 participants had to yet be excluded from the final dataset for not meeting the reliability criteria. This was either because they saw neither the Flash Tap or the Flash Beep illusion once the experimental trail began, or they saw the Flash Beep but not the Flash Tap (it was very rarely the other way around). This obviously meant that the work conducted could not be completed as efficiently as was intended. This does beg the question as to why this happen and would there be any way to prevent this amount of wastage in future experiments?

Variations among individuals in terms of their likelihood of experiencing the illusion have been found and reported within the literature. For example, Lange, Keil, Schnitzler, van Dijk and Weisz (2014) found there to be an inverse correlation between alpha power and the susceptibility to visual illusions. That is people with a higher alpha power are less likely to experience the illusion than those with a low power, this is something that was later replicated by Cecere et al., (2015) who found a moderate negative correlation between Flash Beep susceptibility and alpha power ($r = .52$). Furthermore, research has also suggested a link between grey matter density and proneness to the illusion. De Haas, Kanai, Jalkanen and Rees (2012) found that participants who had a lower volume of grey matter in their early visual cortex were more prone to the illusion overall. As such it is reasonable to assume that there are functional differences in individual's brains that contribute to a higher susceptibility to the Flash Tap illusion as well as the Flash Beep. Perhaps one of these functional differences is the transmission rates of the stimuli. There would be a minor difference between the transmission rate of tactile information (as the neural signal representing the stimulation needs to travel up the arm to reach the brain) and the auditory information (which needs to go from ear to brain, a much shorter distance). As such the paradigm may simply need some optimisation, for example for us to bring the tactile stimulation forward slightly so the tactile and auditory information reaches the brain at the same time relative to the visual stimulus.

There are other potential optimisations that could go some way to improve the paradigm that we used. Much effort and care was taken to ensure that the participant's stimulated hand was as close to the centre of the screen and the flashing disc. However, it is possible to get the hand even closer, via a raised platform or by replacing the CRT monitor with a flat LED or LCD screen placed horizontally upon on the desk, where a participant could place their hand over, right next to the flashing disc. Alternatively, another potential solution to this issue would be to abandon the double flash paradigm all together for a more reliable method. One potential successor could be simultaneity judgements such as those used by Scarpina et al., (2016) whereby participants must state whether they believed certain stimuli was or was not presented at the same time. However, this method may fall for the same issues, such is the case where an explicit response is required by the participant. As such it is perhaps desirable for investigations into this matter to utilise a more implicit multisensory task, whereby behavioural measures are taken from automatic responses as opposed to asking the participant for their explicit response. This would be beneficial for two reasons, firstly it would potentially mean we could expand the number of participants whom would be eligible for the study. This is as it would hopefully reduce the amount of participant wastage due to them not perceiving the illusion reliably. Secondly it would also be potentially beneficial removing any doubt as to whether or not demand characteristics had adversely affected our results, as this would be based on automatic and hence uncontrollable measures.

Another somewhat unexpected phenomenon is the difference between the left and the right hands. It is clear to see that the two hands are indeed linked in terms of the temporal windows we uncovered, as denoted by the moderately strong correlation that we found. However, there was a significant difference between the hands when initially tested, this difference diminished post-TMS when the window for the left hand increased, and as the window for the right hand surprisingly decreased. This does raise the question of why was there such a difference between hands initially, and why did the right hand window decrease as a result of the stimulation, despite the stimulation taking part on the right side of the brain.

One possible explanation for the initial difference in the left and the right hand is simply the increase in the sensitivity of the dominant hand. Given how only 1 out of our overall sample of 17 participants was left handed there is a very clear imbalance between the hands that were tested, with the majority of all participants having their right hand as their dominant hand. The dominant hand is given a greater spatial mapping across the brain, accounting for a higher amount of white matter in the contralateral area of cortex (Büchel et al., 2004) in this case the left hemisphere. This is theorised to account for the many differences that have been found between the non-dominant and dominant hands. Özcan, Tulum, Pınar, & Başkurt (2004) discovered many differences between the dominant and non-dominant hand, including the pain threshold, grip strength, dexterity and touch pressure. Given this evidence it is not impossible that there is also a difference in the influence upon the illusory effect. In order to re-test the influence of hand tapper placement in future experiments it would perhaps be beneficial to carefully select participants based upon their handedness. This would be to ensure that we have an equal number of left handed and right handed participants.

Firstly, if this explanation is correct we should expect in this case to see no difference between the two hands. Secondly if this is the case we should also be able to split the group along handedness and compare the two subgroups, with the view of hoping to see a wider window for the left hand for the left handed people and a wider window for the right handed widow for the right handers.

As stated, post-TMS the right hand temporal window was reduced, and whilst this did not quite reach significance it is nonetheless and interesting quirk. This is especially the case as the right hemisphere was stimulated, suggesting that the only difference should be seen in the left hand. However, some perhaps surprising research has suggested that there may also be an ipsilateral effect of the motor cortex on arm and hand movement, potentially explaining the effect that was seen in this research (Pollok, Gross & Schnitzler, 2006). Further to this, research has also indicated that there is a possibility of an ipsilateral effect when using TMS (Kobayashi, Hutchinson, Theoret, Schlaug & Pascual-Leone, 2004; Rizzo et al., 2011), as such this may be what we are observing here. As such in order to test this we could look to re-investigate this phenomenon by stimulating the left hemisphere, in order to observe the changes upon the right hand temporal window. As such we could then once again look to see any difference between the two hands pre-TMS and once again to investigate any changes post-TMS. In this case if this potential explanation is true we should expect to see a corresponding widening of the temporal window for the right hand and also possibly a corresponding reduction of the temporal window for the left hand.

The final unexplained phenomenon that was uncovered during this research is the lack of correlation between the change in left hand window and change in beta frequency. Obviously this is problematic for us, we have demonstrated that a relationship between beta and the window appears to exist and that it is possibly a causal relationship. However, we cannot statistically attribute the change in the temporal window we have observed directly to the change in the beta frequency that we produced. This means that in this investigation we have not been able to fully uncover the true nature of the relationship. It is possible that the change in window and beta are related but their relationship is not simple. In order to further investigate this point, we must now look into investigating the correlation between numerous denominations of the change values, such as change index or proportion of change, in an attempt to uncover the true nature of this relationship. We must also consider the possibility that the relationship is simply non-linear. That is the relationship between change in behaviour and change in frequency could be of a more logarithmic nature.

Obviously with all areas of research, the question arises as to what happens next. In this case further developing our understanding of the temporal binding window and thereby developing our understanding of multisensory integration is crucial. With such a new topic there is still very much to learn. As a result of this a few potential further investigations and a potentially exciting interventional approach will henceforth be presented.

In this research we have found differences in, and relationships between the temporal binding windows for different multisensory tasks. For example, we appear to have demonstrated a functional difference between the Flash Tap window and the Flash Beep window, alongside a potential relationship between the two. We have also potentially uncovered two different Flash Tap windows, with the investigation of both the right and the left hand, as well as a correlation between the two. As such it would be interesting to now fully develop our understanding of multisensory binding windows in other domains. This can be seen in the research conducted by Hötting and Röder (2004). These researchers were able to demonstrated that, in a similar vein to the Double Flash illusion participants could be lured into perceiving two taps upon their index finger when only one was in fact experienced. This occurred when the tap was simultaneously presented alongside a quick double beep.

Furthermore, in the study by Bresciani et al., (2008) it was once again found that irrelevant visual stimuli could influence the number of perceived taps or tones experienced, also the number of tones perceived could be influenced by the presence of an irrelevant tactile stimulus. As such it appears that the fission effects of the so called "double flash" illusion that has been investigated here is far from exclusive to the visual domain. In this case it would perhaps be useful to ascertain the temporal windows for all of these similar illusory effects, by repeating the methods of the current study on the other, previously discussed illusory effects that have also been found in the literature. As such this research could look to infer the temporal windows for these respective illusory effects and attempt to uncover a relationship between neural oscillations in order to further increase our understanding of the link between these oscillatory processes and multisensory processing. Also we could again look to investigate their comparative differences to one another in order to attempt to obtain evidence of a relationship between these windows and a corresponding neural oscillation in the corresponding multisensory area.

Once other potential windows have been uncovered we could then look to assess their properties and investigate them all in relation to one another. As previously discussed we know that temporal window abnormalities can be linked to abnormal behaviour, such as autism or obesity (Foss-Feig et al., 2010; Scarpina et al., 2016). However in both these cases only a number of auditory-visual tasks were utilised. Therefore, we are currently unaware if there is any connection between these conditions the other potential temporal binding windows that have been proposed here. Furthermore, as discussed, numerous windows may exist and as a result it would be interesting to investigate the properties of these windows and attempt to investigate them in terms of something greater than the relatively low level effect that is the double beep illusion. For example, we could look to find out whether they are all related to one another, and we can look to see if one temporal window corresponds to the aforementioned abnormalities more than the other windows.

One potential future study could look to investigate the numerous temporal windows that have been put forward and any other potential windows that exist and investigate their properties. We could then focus more heavily on participants who were found to have particularly large temporal windows, these then could be compared to participants who had a particularly small temporal windows. This would be to ascertain whether the individual magnitude of the window itself has any behavioural function or advantages aside from their link to these illusions and the previously mentioned abnormalities. For example, participants who have a larger temporal window may have greater sensory acuity as they have a larger period of time in which they can merge sensory information. These people also may be more susceptible to other illusory effects discussed previously because of their larger period of time in which they have to co-modulate sensory information. Nonetheless it would be highly interesting and enlightening to investigate ways in which people who have a particularly large temporal window are different to those who have a smaller one, and also to what function, advantage or disadvantage these windows have depending on their relative size.

Given how we have been able to demonstrate an ability to experimentally manipulate an individual person's temporal binding window we should now look to uncover practical applications of the method. One potential application could be to apply this to the psycho-physical conditions that were mentioned in the introduction, for example, anorexia, schizophrenia, autism or obesity (Gaudio et al., 2014; Ross et al., 2007; Kwakye et al., 2011; Scarpina et al., 2016). We have found that a brief 15 minute CCPAS protocol can induce a temporary widening of the temporal binding window, we should now look to see whether we could induce a similar corresponding reduction of the window using the same method. A widening of the window is associated with general aging and degradation of the multisensory system (Hillock, Powers & Wallace, 2011), occasionally this can be the result of illness such as obesity or autism (Scarpina, et al., 2016; Foss-Feig et al., 2010), however if we are able to use the same method to shrink the window then this may act as an appropriate interventional method to the degradation of the perceptual system.

TMS has been used in treatments before, most notably in neurological conditions such as depression (Kolbinger, Höflich, Hufnagel, Müller, & Kasper, 1995; George et al., 2000). This method has been tried and tested and is now approved by the Food and Drug Administration in the United States for widespread use and treatment of this condition (Horvath, Mathews, Demitrack & Pascual-Leone, 2010). However as yet there is little research on the method in terms of the treatment of other conditions such as obesity. This report will now look to propose a potential further study on obesity and a potential interventional approach that may be possible as a result of the current research on the CCPAS protocol and the manipulation of the temporal window. Obesity is certainly a huge issue at the moment, especially in British culture. According to the NHS Britain spent an estimated £27 billion indirectly on the treatment of obesity in the year 2015, with this figure expected to rise to £50 billion by the year 2050, with around 60% of adults being classed as either obese or overweight, as such research into this condition is imperative.

Recent research into obesity has uncovered a tendency to suffer with cognitive deficits as a result of neuro-inflammation (Miller & Spencer, 2014). These cognitive deficits culminate in a degradation of perceptual processes (Costantini, Scarpina, Migliorati, Mauro & Marzullo, 2015), given how this is the case it is perhaps surprising that there is very little research on the link between obesity and multisensory processing. This is perhaps even more surprising given how such a multisensory condition obesity is. The act of eating is very much multisensory, with the perceived flavour of the food depending on many factors, such as the feel of the food in the mouth, the visual attractiveness of the food and the sound it makes when being eaten (not to mention the taste and smell itself) (Spence, 2013). Furthermore, body perception and image also relies on multisensory processing such as somatosensory, visual, auditory and vestibular processes (Murray, Wallace, Aspell, Lenggenhager & Blanke, 2012). Both of these processes have been shown to be altered in the obese with many people being classed as “supertasters” with an increased sensitivity to flavour (Pasquet, et al., 2007). Furthermore, body image and perception was found to be highly associated with obesity and eating disorders (Harriger & Thompson, 2012). Finally, as has been previously stated a widening of the temporal binding window has been linked to some of the characteristics of obesity (Scarpina, et al., 2016)

Some success has been found when attempting to use the correction of faulty perceptual processing as an interventional approach to the condition. Serino et al., (2016) looked specifically to focus of the faulty body perception aspect of the illness. In an attempt to improve body satisfaction, the researchers introduced a virtual reality protocol, effectively swapping the patient’s body with that of a more desirable one. After this protocol the patient reported an increased motivation to lose weight and by the end of the investigation had lost 3.7% of her original body weight. This preliminary evidence suggests that by working on sensory processing the effectiveness of obesity treatments may be increased. As such further research would look to focus on the multisensory aspect of the condition.

We would first aim to investigate the temporal window by asking the obese participants to perform the illusory tasks (or perhaps another more reliable task, perhaps even an implicit task as proposed earlier in the report) and compare them to healthy weight controls. Based on previous research on this condition we would expect to find the obese participants to have a significantly wider temporal binding window when compared to the healthy weight controls (Scarpina, et al., 2016). Once this analysis had been completed (assuming our findings are consistent with our hypothesis) we would look to use the CCPAS in order to produce a reduction of the temporal binding window in an attempt to return multisensory processing to something resembling normality. As such we may be able to return some of the faulty processes (e.g. taste, smell, proprioception) associated with the condition to normal, with the ultimate aim of correcting the destructive behaviour associated with the condition and hopefully as a result reducing the severity of the symptoms in some patients.

In conclusion what the researchers in this study set out to investigate was the properties of the Double Flash Illusion, predominantly the Flash Tap illusion but also with the aim of confirming previous findings on the Flash Beep illusion. We were able to replicate previous findings that suggest a relationship between the peak alpha frequency in the occipital cortex and the temporal window for the Flash Beep illusion. We were also able to replicate previous research that had suggested a similar relationship between the beta frequency and the Flash Tap temporal window. We also put forward tentative evidence to suggest that this relationship is causal, as a result we hypothesise that the peak occipital beta frequency is responsible for some of the properties of the Flash Tap window.

In doing this we also provided further information on the potential uses of the CCPAS method of neuromodulation.

Some of the findings were not consistent with our hypothesis and provide a basis for further work on the topic. For example, we should now look to investigate further the difference between the left hand and the right hand in terms of the illusion. We should also look to investigate further why we failed to find a correlation between the change in beta and the change in left hand window. It is also imperative that future research looks to include control conditions.

Further research could look to provide positive applications for these findings. One example would be to use what we have found here to act as a basis for the investigation of the temporal windows for other illusory tasks. Another potential further study would look at using the CCPAS method in order to provide interventional approaches to debilitating conditions that have in the past been linked to faulty multisensory processing and abnormalities in the temporal binding window. As such a potential investigation into obesity was proposed, this would look to investigate how the Double Flash illusion could look to uncover the properties of the condition. This would then potentially pave the way for us to utilise the CCPAS method in a similar way to the current study in an attempt to reduce the temporal binding window and potentially alleviate some of the characteristics of the condition.

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