Perceptual training as means to assess the effect of alpha frequency on temporal binding window.

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Abstract

For decades it has been shown that alpha frequency is related to temporal binding window and currently such is the mainstream viewpoint (Cecere et al., 2015; Gray & Emmanouli, 2020; Hirst et al., 2020; Keil, 2020; Keil & Senkowski, 2017; Migliorati et al., 2020; Minami & Amano, 2017; Noguchi, 2022). However, recently this stance has been challenged (Buergers & Noppeney, 2022). Moreover, both stances appear to have their limitations regarding the reliability of results. Therefore, it is of paramount importance to develop new methodology to gain more reliable results. Perceptual training seems to be such a method which also offers significant practical implications.

For decades vast amount of research has focused on exploring neural correlates of temporal binding window (time frame within which sensory information from different modalities is integrated). The mainstream view of the literature is strongly suggesting alpha frequency to be the neural mechanism of the temporal binding window (Cecere et al., 2015; Gray & Emmanouli, 2020; Hirst et al., 2020; Keil, 2020; Keil & Senkowski, 2017; Migliorati et al., 2020; Minami & Amano, 2017; Noguchi, 2022). However, Buergers and Noppeney (2022) recently challenged this view, stating that the existing findings are confounded with bias and there is no evidence for the relationship between temporal binding window and alpha frequency. Therefore, it is crucial to evaluate the methodology of both stances.

As previously stated, the predominate stance currently is that alpha oscillations are the neural mechanism of temporal binding window (Cecere et al., 2015; Gray & Emmanouli, 2020; Hirst et al., 2020; Keil, 2020; Keil & Senkowski, 2017; Migliorati et al., 2020; Minami & Amano, 2017; Noguchi, 2022). It has been suggested (Van Rullen, 2016) that a higher alpha frequency leads to narrower oscillatory cycle, and stimuli that fall into the same oscillatory cycle are bound into a single percept, while two stimuli falling into separate cycles are separated into two distinct temporal events. That is, the temporal binding window decreases as the alpha frequency increases. Further support is believed to be provided by studies directly investigating relationship between alpha frequency and temporal binding window.

Correlational studies examining temporal binding window and alpha frequency include those conducted by Cecere et al. (2015), Keil and Senkowski (2017)**,** Venskus and Hughes (2021) and Noguchi (2022). Cecere et al. (2015), Keil and Senkowski (2017) and Venskus and Hughes (2021) used double-flash illusion, to assess temporal binding window and alpha frequency was measured via EEG. Double-flash fission illusion involves simultaneous presentation of visual and auditory stimuli followed by a presentation of a second auditory stimulus after various time delays. If the second auditory stimulus occurs within the individual’s temporal binding window not just the first auditory stimulus is integrated with the visual stimulus but also the second auditory stimulus. This creates an illusion whereby participants report experiencing two flashes despite only one flash being presented. The delay at which an individual no longer perceives two flashes is taken as the width of their temporal binding window. Researchers concluded that individuals with an increased alpha frequency showed decreased width of the temporal binding window. In addition, a recent study conducted by Migliorati et al. (2020) concluded that individual alpha frequency is not just associated with temporal binding window when audio-visual integration is concerned but also in case of visuo-tactile integration. More specifically, Migliorati et al. (2020) used a visuo-tactile simultaneity judgment task to assess temporal binding window while individual alpha frequency was recorded during the task using EEG. Researchers argued the findings to indicate that the increased individual alpha frequency is associated with decreased temporal binding window. Whereas Noguchi (2022) extended this research area and investigated neural correlates of temporal binding window in fission illusion (1 flash and 2 beeps) and fusion illusion (2 flashes and 1 beep). Findings showed that as alpha frequency increased temporal binding window decreased in fission illusion and as beta frequency increased temporal binding window decreased in fusion illusion. Noguchi (2022) concluded findings to indicate two separate temporal binding windows, with alpha frequency being associated with fission of stimuli and beta frequency being associated with fusion of stimuli.

Furthermore, researchers argue that there is also causal evidence to support the link between individual alpha frequency and temporal binding window. In addition to recording individual alpha frequency via EEG, Cecere et al. (2015) used neuromodulation to alter the individual alpha frequency. More specifically, transcranial alternating current stimulation (tACS) was used at either each participant's individual alpha frequency or individual alpha frequency +/-2Hz. Hence, participants received continuous tACS at one of three possible frequencies throughout the double-flash illusion task. Researchers concluded the findings to indicate that the neuromodulation (via tACS) of the individual alpha frequency alters temporal binding window accordingly (increased alpha frequency is associated with decreased temporal binding window). Similarly, Venskus et al. (2021)

applied occipital tACS at either 14Hz or 8Hz and concluded that 14Hz tACS stimulation was associated with decreased temporal binding window and vice versa.

However, it is possible that stimuli presented during tasks has influenced the alpha frequency rather than alpha frequency regulating the perception of the stimuli. Gray and Emmanouli (2020) showed that alpha frequency is not altered by the bottom-up stimulation (stimuli presented during the tasks). Instead, it was concluded that alpha frequency drives the perception of the stimuli internally regardless of changes in the environment. This provides support for the above studies. However, it is still not clear whether the alpha frequency manipulation was successful during tACS stimulation. Therefore, robust conclusions cannot be made regarding the alpha frequency being the neural correlate of the temporal binding window. Solution to this, and consequently support for the above studies, has been provided by Minami and Amano (2017). Researchers combined the amplitude modulation of transcranial current stimulation (AM-tACS), which reduces an artifact near the AM frequency, with the temporally extended signal space separation (tSSS) method, which is a noise reduction technique, and showed that tACS stimulation successfully manipulates alpha frequency. Moreover, research demonstrated that alpha frequency was visually experienced as an illusory jitter in the motion-induced spatial conflict. Subsequently, it was concluded that the alpha frequency in creating temporal characteristics of visual perception.

It is also worth noting that research from clinical population have claimed support for the relationship between alpha frequency and temporal binding window. Numerous studies have showed that individuals with schizophrenia spectrum disorders have altered temporal binding window (Ferri et al., 2018; Haß et al., 2017) and altered alpha frequency (Dimitriadis, 2021; Jin et al., 2006). Despite the existing literature claiming support for the link between alpha frequency and the temporal binding window recently Buergers and Noppeney (2022) showed that the existing research is confounded with bias.

Recently Buergers and Noppeney (2022) found that alpha frequency does not substantially influence the temporal binding window. This conclusion was derived from a multi-day study using a series of two-flash discrimination experiments and EEG experiments conducted to assess whether alpha frequency influences temporal binding window within and across the senses. Buergers and Noppeney (2022) argue that previous studies, showing support for the link between alpha frequency and temporal binding window, cannot decipher whether the results are due to link between alpha frequency and temporal binding window or if this relationship is mediated by bias. Bias here is explained as top-down prior expectations and sensory-driven mechanisms of reliability-weighted integration. The former can lead to predisposition to perceive in a particular way (i.e. two flashes rather than one) as well as lead to particular cost-reward values (i.e. better to miss two flashes than incorrectly identify two flashes), and this is depending on prior experience of the observer. The later leads to integration of multisensory information by averaging independent sensory estimates according to their reliabilities. However, despite the rigorous methodology employed by Buergers and Noppeney (2022), the findings seem to also contain some confounding aspects.

Buergers and Noppeney (2022) study was conducted over multiple days and utilized multiple different yet similar tasks to assess temporal binding window via implicit integration of multisensory information. That is, the study included three experiments (two-interval forced-choice, yes-no with variable SOAs and yes-no at perceptual threshold), with each experiment comprising one or two flashes in three sensory contexts (no beep, one beep, two beeps). Participants were asked to report perceived number of flashes. Given that participants were presented with different tasks, each asking to make judgements regarding the number of flashes perceived, over multiple days can lead to strong learning effects. Firstly, individuals may have learned to be better at the tasks by simply completing them on numerous occasions. Secondly, individuals may have compared their judgements across the tasks. This possibly could lead to the findings being confounded as the tasks may reflect these learning effects instead of the temporal sensitivity.

After scrutinising the existing studies, it is apparent that numerous factors can influence the accuracy of the findings regarding temporal binding window. Hence, more reliable methodology needs to be developed. One potential means via which relationship between temporal binding window and alpha frequency can be reliably investigated seems to be perceptual training.

Perceptual training (simultaneity judgement task) (Powers et al., 2009) involves judging stimuli as simultaneous or non-simultaneous with performance-based feedback being provided. In particular, visual and auditory stimuli are presented with SOAs ranging from - 150ms (auditory stimulus leading) to 150ms (visual stimulus leading) in 50ms intervals. SOAs are presented randomly and not equally distributed (the veridical simultaneous condition had a 6:1 ratio to any of the other 6 non-simultaneous conditions). In this way there is a random and equal likelihood of simultaneous/non-simultaneous conditions, minimizing concerns about response bias. Participants are asked to judge whether the flash and the beep are presented together or separately. They are also informed that they will receive feedback once they have made the response and told to use this feedback to become better at determining whether the flash and the beep occur together or separately. Feedback involves participants being presented with either the phrase `Correct`, green in colour, or `Incorrect`, red in colour. In total perceptual training lasts for approximately an hour.

Based on the characteristics of perceptual training, it seems to be a technique that is likely to induce structural neuroplasticity given it is based on learning and development. Structural neuroplasticity refers to structural changes (Buonomano & Merzenich, 1998; Demarin & Morovic, 2014; Shaw, 2001). In particular, it allows for permanent physical changes in the neural system due to learning and development. On the individual neuron level physical changes involve new neural connections, different densities of nerve cells and varying strengths of neural connections. When considering clusters of neurons, physical changes observed are the same as on the individual neuron level but involve clusters of neurons, thus rewiring large regions and reorganizing the nervous system at multiple levels. Moreover, cell assembly theory (Löwel & Singer, 1992) argues that recurring synaptic connections grow more efficient due to stronger nerve connections being established. This dynamic process allows one to learn from and adapt to different experiences. For example, Mechelli et al. (2004) showed that learning a second language increases the density of grey matter in the parietal cortex. They also found that as the fluency increased so did the strength of the structural reorganization. Famously, Maguire et al. (2000) found that London taxi drivers had significantly larger posterior portion of the hippocampus (involved in processing spatial memories) than non-taxi drivers. Moreover, the size of the difference was positively correlated with the amount of time spent as a taxi driver.

Temporal binding window has been shown to be decreased following perceptual training. More specifically, De Niear et al. (2018) and Stevenson et al. (2013) showed a decrease in temporal binding window immediately after perceptual training. Moreover, Powers et al. (2009) and Zerr et al. (2019) extended these findings to stable decrease in temporal binding window a week after the perceptual training. However, it must be noted that a later study by Powers et al., (2016) did not find temporal binding window to be altered by perceptual training a week after. The above leads to conclude that perhaps changes in cognitive processes (temporal binding window) diminish after approximately a week. The reasoning behind such a conclusion is that for learning to become permanent it should be established within a neural system (Swart et al., 2015). That is, if one considers that the neural system drives cognitive processes, any changes in cognitive processes in response to learning and development can only be sustained permanently if corresponding neural mechanisms have also been changed permanently. It has been indicated that considerable amounts of learning and development (three or more months) is required to achieve permanent neural changes (Swart et al., 2015). Given that the discussed studies employed only brief perceptual training permanent neural changes would not be expected. Instead, it would be expected that neural changes are temporary and fading as time progresses. Given Powers et al. (2016) findings and existing literature in neuroplasticity (Swart et al., 2015) it can be argued that neural changes (alpha frequency) fade within approximately a week and consequently so does the changes in corresponding cognitive processes (temporal binding window).

Researchers argue that the reduction effect in temporal binding window is observed due to the perceptual training shifting the point of subjective simultaneity (PSS) (the discrepancy at which two stimuli are perceived as simultaneous) towards the optimum (De Niear et al., 2018; Powers et al., 2009; Stevenson et al., 2013; Zerr et al., 2019). The argument is that by being provided the feedback of their judgement individuals learn what constitutes simultaneous and non-simultaneous stimuli. As such developing better ability to discriminate between the stimuli. This is being reflected in the psychometric curve where psychometric function`s inflection point (a point on the curve in which the concavity changes) corresponding to PSS is taken as the width of the temporal binding window. That is, findings showed that inflection point was lower following perceptual training. Additionally, the slope of the psychometric curve, with steeper slope indicating less variability in the responses of PSS, was observed following perceptual training. What is more, the shift in PSS, if due to the enhanced temporal sensitivity, supports the notion that alpha frequency is the neural correlate of temporal binding window. This is due to the proposition (Van Rullen, 2016) that a higher alpha frequency leads to narrower oscillatory cycle, and stimuli that fall into the same oscillatory cycle are bound into a single percept due to being perceived as simultaneous and vice versa. Yet it still not clear whether the decrease in temporal binding window (the decrease in PSS) following the perceptual training is due to the enhanced temporal sensitivity or due to change in criterion shift that has come about from the feedback provided. Moreover, effect of perceptual training on alpha frequency has not been previously explored.

Given that perceptual training induces structural neuroplasticity changes and if alpha frequency is the neural correlate of temporal binding window, alpha frequency should be affected similarly to temporal binding window following perceptual training. It would provide robust evidence in favour of alpha frequency being the neural mechanism for temporal binding window. This conclusion is reached as this type of methodology reduces the weight assigned to limitations regarding the measurements of temporal binding window (top-down prior expectations, sensory-driven mechanisms of reliability-weighted integration (Buergers & Noppeney, 2022) and learning effects). That is, if temporal binding window and alpha frequency are similarly modified by perceptual training these confounding aspects would no longer be determining factors to question the role of alpha frequency in temporal binding window. Given that both processes shift accordingly following perceptual training and has sound theory in support of such shift indicates strong relationship between alpha frequency and temporal binding window. Moreover, if such effect is shown to be permanent it would provide further support for the effect of alpha frequency on temporal binding window as it would strengthen the theory that permanent changes in alpha frequency result in permanent changes in temporal binding window.

To assess the above proposition, it is suggested for further studies to explore effect of alpha frequency on temporal binding window by providing participants with perceptual training over three or four months with alpha frequency and temporal binding window being measured prior and after perceptual training sessions. However, one ambiguity still remains. Previous research has solely focused on exploring perceptual training effects of temporal binding window in one spatial location. This results in lack of evidence of whether perceptual training in one spatial location results in the improvement across the visual field. Only if the improvement is seen across the visual field alpha frequency is expected to change accordingly if it is to be the neural mechanism of the temporal binding window. To address this, it is proposed that double-flash illusion is adapted. That is, visual stimuli should be provided in various spatial locations. This will allow to assess if the perceptual training in one spatial location results in the improvement across the visual field.

In addition, there are potential practical implications if it is to be discovered that alpha frequency and temporal binding window can be permanently enhanced via perceptual training. Namely, it would allow to focus research on exploring how perceptual training can be used in assisting individuals with mental health disorders (i.e. various psychosis) where these processes are impaired. It has been shown that individuals with schizophrenia have less precise temporal sensitivity (Ferri et al., 2018; Haß et al., 2017) and decreased alpha frequency (Dimitriadis, 2021; Jin et al., 2006) and these altered states have been argued to be possible contributors towards the positive symptoms (hallucinations and delusions) experienced. It is of paramount significance to identify means other than the medications to alleviate the symptoms. Compliance with the medications is reported to be very low with detrimental consequences (Vega et al., 2021). More specifically, non-compliance with antipsychotic medication is associated with return of the psychotic symptoms and consequently an increase in suicidal behaviour, hospitalisation and mortality in schizophrenic patients (Warriach et al., 2021). Non-compliance seems to be largely due to hallucinations and delusions leading the individual to believe that medication is harmful to them or that they are not ill at all (Kokurcan et al., 2020)**.** Hence, alleviation of positive symptoms would lead to better compliance with the medication.

Given the above it appears that current methodology used to assess the effect of alpha frequency and temporal binding window has significant limitations. However, the proposed methodology suggesting perceptual training as means to assess this relationship seems to overcome these aforementioned methodological limitations. Moreover, such methodology lays the path for potential practical implications regarding treatment of individuals with various psychotic traits.

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