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Zapping the gap: Reducing the multisensory temporal binding window by means of transcranial direct current stimulation (tDCS)

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ABSTRACT

Synchrony among the senses lies at the heart of our possession of a unified conscious perception of the world. However, due to discrepancies in physical and neural information processing from different senses, the brain accommodates a limited range of temporal asynchronies between sensory inputs, i.e. the multisensory temporal binding window (TBW). Using non-invasive brain stimulation, we sought to modulate the audio-visual TBW and to identify cortical areas implicated in the conscious perception of multisensory synchrony. Participants performed a simultaneity judgment task while experiencing anodal (Experiment 1) or cathodal (Experiment 2) transcranial direct current stimulation (tDCS) over parietal and frontal regions. The results demonstrate that stimulating the right posterior parietal cortex significantly reduces the audio–visual TBW by approximately 30%, thereby causally linking this region to the plasticity of the TBW. This highlights a potential interventional technique for populations with a wider TBW, such as in autism and dyslexia.

1. Introduction

Experiencing the world in a manner that effectively integrates and intertwines the multiple streams of information coming from different sensory modalities is one of the most fundamental aspects of the human perceptual experience. A critical property of the coherent conscious perception of a multisensory stimulus as a unified object or event is that the sensory inputs are perceived to be synchronous in time and space. In particular, temporal coincidence has been shown to be essential in order for the brain to distinguish between a single perceptual event and an array of independent ones (de Gelder & Bertelson, 2003; Sekuler, Sekuler, & Lau, 1997). This is especially important given the discrepancies in physical attributes, sensory transduction, and neural mechanisms involved in the processing of information from different senses (Vroomen & Keetels, 2010). As a consequence, the perceptual system is built to accommodate a limited range of temporal asynchronies between multisensory inputs, suggesting the existence of a temporal window that sustains the perception of multisensory integration (Spence & Squire, 2003; van Wassenhove, Grant, & Poeppel, 2007). Within this multisensory temporal binding window (TBW), there is a higher probability that stimuli from different modalities are integrated to form a singular multisensory percept, despite a lack of absolute temporal simultaneity. Indeed, Zmigrod and Hommel (2011) have demonstrated

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that when participants are exposed to auditory and visual stimuli with a stimulus onset asynchrony of up to 350 ms, audio-visual binding occurs.

While the flexibility of the audio-visual temporal binding window has been documented by several studies, depicting it can be influenced by exposure to audio-visual asynchrony in both infants and adults (Fujisaki, Shimojo, Kashino, & Nishida, 2004; Lewkowicz, 2010; Navarra et al., 2005), experimental manipulation of the TBW has so far only been successfully conducted through a perceptual training paradigm involving extensive feedback training (Powers, Hillock, & Wallace, 2009). In this paradigm, participants underwent an intensive training in a forced choice version of the audio-visual simultaneity judgment task, lasting a total of five hours. This method was able to narrow the size of the multisensory temporal binding window, suggesting the potential for an interventional procedure to modulate the TBW. Nevertheless, no study has experimentally manipulated the TBW through neuroscientific techniques, and a lack of clarity remains regarding the brain regions and mechanisms that underlie this adaptive shrink and stretch of the multisensory temporal window of integration.

The question of how the brain achieves the perception of multisensory integration, and in particular the specific brain regions that are implicated in the associated processes, is now increasingly being tackled through non-invasive brain stimulation methods such as transcranial magnetic stimulation (TMS; Esterman, Verstynen, & Robertson, 2007; Muggleton, Tsakanikos, Walsh, & Ward, 2007) and transcranial direct current stimulation (tDCS; for review see Bolognini & Maravita, 2011). tDCS enables modulation of neural excitability in specified cortical regions, and causes only minor irritation. By delivering low-intensity electric current to the scalp via electrodes, tDCS is thought to enhance cortical excitability through anodal stimulation and diminish it with cathodal stimulation (Nitsche et al., 2003; Romero Lauro et al., 2014). In comparison to TMS, tDCS involves a significantly less painful experience for the participants and has fewer adverse side-effects (Paulus, 2011, 2014). Hence, studying performance on multisensory integration tasks while delivering tDCS opens up the opportunity to investigate the causal involvement of brain regions in multimodal processing, building upon the knowledge obtained from neuroimaging and behavioral studies.

The present study has two primary aims; firstly, to investigate the possibility of modulating the audio-visual temporal binding window via a non-invasive brain stimulation technique, tDCS, and secondly, to identify brain regions implicated in the perception of multisensory synchrony. The experiments use an audio-visual simultaneity judgment task, which participants perform while experiencing polarized stimulation over specific cortical areas. In particular, we investigated the posterior parietal cortex (PPC) and the dorsolateral prefrontal cortex (DLPFC), which have been previously associated with the detection of temporal asynchrony in auditory-visual stimulus onset (Bushara, Grafman, & Hallett, 2001; for review see Calvert, 2001). In addition, neurostimulation studies have linked the DLPFC to cognitive control processes related to feature binding (Zmigrod, Colzato, & Hommel, 2014), and have demonstrated the role of the PPC in multisensory integration (Bolognini & Maravita, 2011; Zmigrod, 2014). Thus, using a non-invasive brain stimulation technique, we sought to examine the nature of this crucial yet elusive multisensory temporal binding window.

2. Methods and materials

2.1. Participants

In total, 88 Leiden University students (mean age = 20 years; age range: 18–24 years; 21 men) took part in the study, which was divided into two separate experiments. In Experiment 1, anodal tDCS was delivered ($n = 40$), while in Experiment 2, cathodal stimulation was given ($n = 48$). Subjects received course credits or a financial reward for their participation. The participants were naïve to the experimental procedure and purpose of the study. All participants were right-handed as assessed by the Edinburgh Inventory (Oldfield, 1971) with normal or corrected-to-normal vision. Exclusion criteria included: history of psychiatric disorders, drug abuse, active medication, pregnancy, or susceptibility to seizures. Participants provided their written informed consent to participate in the study, in accordance with the ethical standards of the declaration of Helsinki and approval by the Ethical Committee of Leiden University.

2.2. Experimental design and stimulation procedure

The study has a between-subjects design. Participants were independently recruited for Experiment 1 and 2, where each experiment was composed of four groups with different stimulation conditions. Participants were equally divided and randomly assigned to one of the four groups, three of which involved tDCS stimulation in distinct cortical sites: the right PPC, left PPC, and left DLPFC. All conditions involved a simultaneity judgment task. In addition, a control group performed the same task without receiving stimulation or being connected to the tDCS apparatus. In Experiment 1, tDCS was employed with anodal polarity over the designated cortical area, and in Experiment 2, cathodal stimulation was used.

tDCS was delivered by means of a DC Brain Stimulator Plus (NeuroConn, Ilmenau, Germany) and was applied through a saline-soaked pair of surface sponge electrodes (5 cm × 7 cm). The active electrode was placed over either P4, P3, or F3 (depending on the participant's stimulation group), a location atop the right PPC, left PPC, and the left DLPFC respectively, according to the international 10–20 system for EEG electrode placement. The reference electrode was placed over the contralateral supraorbital area as this montage has been proven to be effective in neurostimulation studies involving multisensory perception (Bolognini, Fregni, Casati, Olgiati, & Vallar, 2010; Bolognini & Maravita, 2011; Zmigrod, 2014; Zmigrod et al.,