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Research paper

Cathodal transcranial direct current stimulation can stabilize perception of movement: Evidence from the two-thirds power law illusion

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HIGHLIGHTS

- We tested the role of the premotor and visual cortices in the 2/3 power law illusion.
- Participants adjusted the velocity of a visual dot while receiving cathodal tDCS.
- Occipital tDCS decreases the illusion variability both within and across participants.

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ABSTRACT

Human movements conform to specific kinematic laws of motion. One of such laws, the “two-thirds power law”, describes the systematic co-variation between curvature and velocity of body movements. Noticeably, the same law also influences the *perception* of moving stimuli: the velocity of a dot moving along a curvilinear trajectory is perceived as uniform when the dot kinematics complies with the two-thirds power law. Instead, if the dot moves at constant speed, its velocity is perceived as highly non-uniform. This dynamic visual illusion points to a strong coupling between action and perception; however, how this coupling is implemented in the brain remains elusive. In this study, we tested whether the premotor cortex (PM) and the primary visual cortex (V1) play a role in the illusion by means of transcranial Direct Current Stimulation (tDCS). All participants underwent three tDCS sessions during which they received active or sham cathodal tDCS (1.5 mA) over PM or V1 of the left hemisphere. During tDCS, participants were required to adjust the velocity of a dot moving along an elliptical trajectory until it looked uniform across the whole trajectory. Results show that occipital tDCS decreases the illusion variability both within and across participants, as compared to sham tDCS. This means that V1 stimulation increases individual sensitivity to the illusory motion and also increases coherence across different observers. Conversely, the illusion seems resistant to tDCS in terms of its magnitude, with cathodal stimulation of V1 or PM not affecting the amount of the illusory effect.

Our results provide evidence for strong visuo-motor coupling in visual perception: the velocity of a dot moving along an elliptical trajectory is perceived as uniform only when its kinematics closely complies to the same law of motion that constrains human movement production. Occipital stimulation by cathodal tDCS can stabilize such illusory percept.

1. Introduction

Human movements present specific geometric and kinematic regularities denoting that they are ruled by a limited number of laws of motion. One remarkable example of such kinematic laws is the two-thirds power law, which expresses the relationship between velocity and curvature of human movements [1]. These two logically independent parameters systematically co-vary dur-

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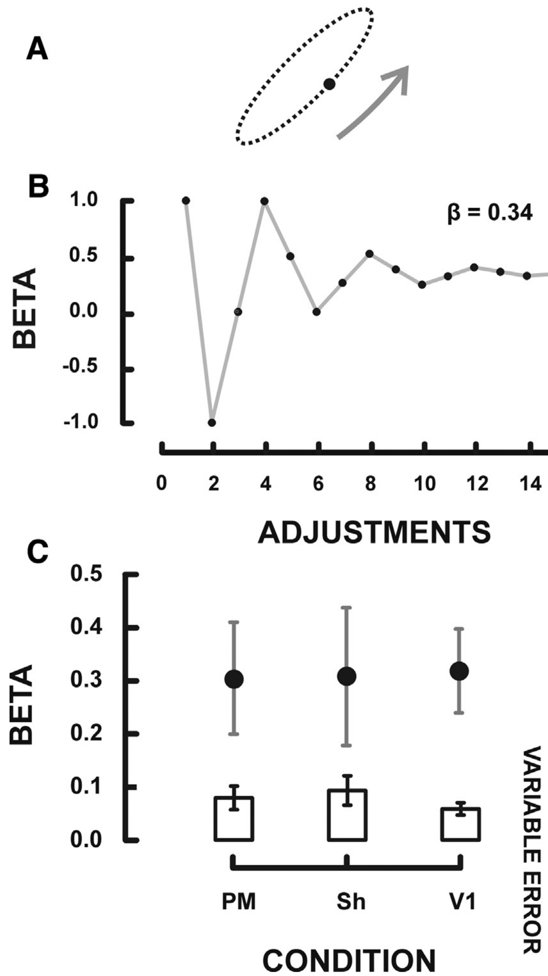

Fig. 1. Stimulus, experimental procedure, and results. Panel A depicts the stimulus. A small dot (0.17°) continuously moved along an elliptical trajectory (eccentricity 0.968, major axis 9.3°), in a counterclockwise direction; its velocity was adjusted by the observer until it appeared to move uniformly along the whole trajectory. Only the dot, but not its trajectory, was visible. Panel B represents the adaptive method employed to control the adjustment steps, in a one-trial example. Panel C illustrates the results. Black circles represent the average β values, whereas their error bars depict the inter-individual standard deviation in each condition. Empty boxes illustrate the individual standard deviation (i.e., the variable error of β) in each stimulation condition, with error bars representing their respective standard error.

ing movement production, so that movement velocity decreases as curvature increases. The relationship between the geometrical form of the movement and its velocity is well characterized by the empirical relation $A(t) = KC(t)^{1-\beta}$, where: A is the angular velocity, C is the curvature, at time t; K is a constant, named the velocity gain factor, which depends on the type of movement. As the exponent β is close to 1/3 in healthy adults, the relationship was named the "two-thirds power law".

Such empirical relation has been observed under a variety of movement tasks and muscle districts involved in the tasks, such as planar drawing movements [1], smooth pursuit eye movements [2], the movement of body segments during locomotion [3], and language articulatory movements [4].

This kinematic invariant is so deeply represented in the brain that it also constrains visual perception of movement [5]: the velocity of a point stimulus is perceived as uniform when its kinematics follows the two-thirds power law. Instead, physically constant speed is perceived as highly non-uniform. Furthermore, recent evidence suggests that even imagined trajectories follow the two-thirds power law [6,7].

Neuroimaging studies have highlighted a marked overlap between the neural circuits mediating the perception of motion complying with the two-thirds power law and those underlying the programming and execution of voluntary movements [8,9]. In particular, Casile and colleagues [9] highlighted a specific role of the left dorsal premotor cortex, the left dorsolateral prefrontal cortex and the medial frontal cortex when observing movements obeying the two-thirds power law performed by computer-generated characters. The tight link between perception and action is further supported by the observation that the two-thirds power law illusion is scaled down in patients with idiopathic Parkinson Disease, as compared to healthy age-matched controls [10]. Furthermore, the perception of point-light motion complying with the two-thirds power law, as opposed to two other kinds of movement kinematics, involves a widespread neural network that includes the left inferior occipital gyrus [8].

Following this evidence, the present study aimed at altering, by means of transcranial Direct Current Stimulation (tDCS) of visual and premotor cortices, the illusory visual perception of motion that follows the two-thirds power law kinematic invariant. A simple dot moving along an elliptical trajectory was employed as a stimulus and the observers' task was to adjust its velocity until it looked uniform along the whole trajectory. During such task, active or sham cathodal tDCS was delivered over the premotor cortex (PM) or the primary visual cortex (V1) of the left hemisphere. If premotor areas are causally involved in the perception of human kinematic invariants [9], decreasing cortical excitability of PM with cathodal tDCS should reduce the two-thirds power law illusion, causing perceptually uniform velocity to become closer to physically constant velocity. On the other hand, cathodal tDCS over V1 could also affect the perception of moving stimuli, maybe counteracting motor-based influences predicted by the two-thirds power law. Indeed, transcranial stimulation of the occipital cortex is known to influence veridical visual perception (see [11] for a review), as well as illusory visual perception brought about by crossmodal stimuli [12,13]. In light of this evidence, one could expect a modulation of the two-thirds power law illusion by occipital tDCS; however, the possible direction (increase vs. decrease of the illusion) of such a modulation is harder to predict as the visual effects of anodal and cathodal tDCS of occipital areas appear to be task-dependent and are still controversial [11].

2. Methods

2.1. Participants

Ten right-handed healthy volunteers (9 females, mean age = 23.7, age range: 20–37) participated to the experiment. All of them had normal or corrected to normal vision and were naïve as to the purpose of the study. None of the participants had neurological, psychiatric, or other relevant medical problems nor any contraindication to TMS or tDCS [14]. Accepted recommendations for the safe use of non-invasive brain stimulation were followed [15]. Each participant provided written informed consent before participating to the study. The protocol followed the guidelines of the Declaration of Helsinki (BMJ 1991; 302: 1194) and was approved by the Ethics Committee of the University of Milano Bicocca (0009874/13).

2.2. Experimental task

The experiment was generated with Matlab and the Psychophysics Toolbox [16] and run on an Asus Intel® Core™2 Quad equipped with an N-Vidia GeForce 9500 GT graphic card and a 22-in LCD color monitor (resolution: 1680 × 1050 pixels, refresh rate: 60 Hz).