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# ENHANCING VERBAL CREATIVITY: MODULATING CREATIVITY BY ALTERING THE BALANCE BETWEEN RIGHT AND LEFT INFERIOR FRONTAL GYRUS WITH tDCS

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**Abstract—Creativity is the production of novel ideas that have value. Previous research indicated that while regions in the right hemisphere are implicated in the production of new ideas, damage to the left inferior frontal gyrus (IFG) is associated with increased creativity, indicating that the left IFG damage may have a ''releasing'' effect on creativity. To examine this, in the present study we used transcranial direct current stimulation (tDCS) to modulate activity of the right and the left IFG. In the first experiment we show that whereas anodal tDCS over the right IFG coupled with cathodal tDCS over the left IFG increases creativity as measured by a verbal divergent thinking task, the reverse stimulation does not affect creative production. To further confirm that only altering the balance between the two hemispheres is crucial in modulating creativity, in the second experiment we show that stimulation targeting separately the left IFG (cathodal stimulation) or the right IFG (anodal stimulation) did not result in changes in creativity as measured by verbal divergent thinking. These findings support the balance hypothesis, according to which verbal creativity requires a balance of activation between the right and the left frontal lobes, and more specifically, between the right and the left IFG. © 2015 Published by Elsevier Ltd. on behalf of IBRO.**

**Key word: tDCS, brain stimulation; inferior frontal gyrus; creativity; divergent thinking.**

## INTRODUCTION

Creativity has been defined as the ability to produce responses that are both novel (i.e., original, rare and unexpected) and suitable (i.e., adaptive and useful according to task constraints (Stein, 1953; Sternberg and Lubart, 1999). According to the two-stage model, the creative process encompasses two parts: a free association process that involves generating ideas, and the monitoring and evaluation of these ideas (Finke et al., 1992). This model of creativity emphasizes the need for a balance between the two parts of the creative process.

It has been suggested that creativity is composed of convergent and divergent thinking (Guilford, 1967). Divergent thinking (DT) involves producing many ideas to a problem which has more than one solution. One example is the Alternate Uses Task (AUT; (Guilford et al., 1978)) in which participants are asked to provide many possible uses for an everyday item, such as a cardboard box. In contrast, convergent thinking (CT) involves finding the one correct and unique answer to a problem which has only one solution. One such task is the Remote Associates Task (RAT; (Mednick, 1962)) in which participants are presented with a list of three presuming unrelated words and are asked to provide the common associate. Like other high-level cognitive abilities, creative thinking has been found to involve a wide array of neural networks in both hemispheres (Howard-Jones et al., 2005; Dietrich and Kanso, 2010; Goldstein et al., 2010; Jung et al., 2010b). So far, examinations of the neuroscience of creativity have yielded diverse findings (Dietrich and Kanso, 2010; Abraham, 2013). A recent meta-analysis of neurological research on creativity pointed toward general right hemispheric superiority in creative thinking and idea generation (Mihov et al., 2010). Indeed, right hemispheric activations have been found in divergent semantic processing (Howard-Jones et al., 2005) and in solving problems with insight (Bowden and Jung-Beeman, 2003). More specifically, the right inferior frontal gyrus (IFG) has been implicated in remote associate thinking such as novel metaphor processing, a process related to verbal creativity (Mashal et al., 2007). Thus, the right hemisphere may act to mediate the free association part of the creativity model specifically related to verbal creativity. This view is supported by neuroimaging studies that show right hemisphere activity in verbal tasks involving the generation of unusual verbs (Seger et al., 2000) and in remote associative thinking (Bowden and Jung-Beeman, 2003).

In addition to findings regarding the role of the right hemisphere, studies have found evidence of left activation in creativity during performance of the AUT, a task of verbal DT (Fink et al., 2009; Benedek et al., 2013) as well as during creativity tasks that usually require mostly right hemisphere activations, such as drawing and designing (Kowatari et al., 2009; Aziz-Zadeh et al., 2013). Furthermore, a recent lesion study involving DT tasks indicated that while lesions in

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*Abbreviations:* ATL, anterior temporal lobe; AUT, Alternate Uses Task; CT, convergent thinking; DT, divergent thinking; IFG, inferior frontal gyrus; mPFC, medial prefrontal cortex; tDCS, transcranial direct current stimulation; TTCT, Torrance Test for Creative Thinking; VF, Verbal Phonetic Fluency; VFT, visual figural task.

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the medial prefrontal cortex (mPFC) were associated with reduced creativity, lesions in the left hemisphere were associated with increased DT (Shamay-Tsoory et al., 2011). These findings are supported by studies of patients with brain damage including stoke (Mayseless et al., 2014) and frontotemporal dementia accompanied by language impairments (semantic dementia, progressive aphasia) who display enhanced artistic creativity following deterioration of left frontotemporal regions (Miller et al., 1996, 2000; Seeley et al., 2008). These reports indicate that damage to left frontal areas, including the left IFG, may have a ''releasing effect'' on creative production, suggesting that these regions are implicated in creativity and may actually ''inhibit'' creativity, perhaps by imposing inhibitory control over the process. Thus, among other processes creative thinking may involve a balance between the right and the left frontal areas. Specifically, verbal creativity has been found to activate the left IFG (Shah et al., 2013) while visual figural creativity was found to activate other left frontal regions including superior frontal gyrus, mPFC and dorsolateral prefrontal cortex (Aziz-Zadeh et al., 2013). Building upon these studies, in the current study we sought to examine the possibility of directly changing levels of verbal creativity in healthy individuals by altering the hemispheric balance of activity over frontal regions.

Several studies that have used non-invasive brain stimulation by means of transcranial direct current stimulation (tDCS) and different types of tasks requiring creativity, including divergent and convergent tasks offer preliminary evidence in support of our model of balance between the right and the left hemispheres. It has been suggested that tDCS alters neuronal membrane potentials thus modulating the excitability of a targeted region (Bindman et al., 1962; Zheng et al., 2011). Anodal tDCS has been reported to increase cortical excitability while cathodal tDCS has been reported to decrease cortical excitability (Nitsche and Paulus, 2001; Nitsche et al., 2003). In line with the balance hypothesis, Chi and Snyder (2011) used bilateral tDCS in a CT study, targeting the anterior temporal lobe (ATL). tDCS was used to decrease excitability (via cathodal stimulation) over the left ATL while increasing excitability (via anodal stimulation) over the right ATL. Results indicate that stimulating bilaterally the ATL can lead to improved performance on a CT task of insight problem-solving. Cerruti and Schlaug (2009) found that the left dorsolateral prefrontal cortex (DLPFC) anodal stimulation was associated with increased performance on a CT task that requires formation of non-evident associations to solve insight-style problems. In contrast, Chrysikou et al. (2013) showed that cathodal stimulation over the left PFC can result in enhanced performance on a DT task. Collectively, these findings seem to indicate that *anodal stimulation* over prefrontal left hemispheric areas may be accompanied by better performance on CT tasks such as insight-related tasks (Cerruti and Schlaug, 2009; Metuki et al., 2012). While *cathodal stimulation* over left prefrontal areas may be accompanied by better performance on DT tasks such as the AUT (Chrysikou et al., 2013). Furthermore, bilateral stimulation of frontal regions can lead to enhanced performance on a CT task (Chi and Snyder (2011)).

In the current study two experiments were conducted to test the balance hypothesis in verbal and figural DT, according to which altering the balance between the left and the right IFG will lead to changes in verbal DT among healthy individuals who underwent different tDCS protocols targeting the IFG. Specifically, we sought to focus on the IFG as previous research has indicated that this area is implicated in categorization and cognitive control (Lupyan et al., 2012), as well as in creative idea generation (Gonen-Yaacovi et al., 2013), creative problem solving (Qiu et al., 2010), selection/control mechanism (Pisoni et al., 2012) and verbal creativity (Jung-Beeman et al., 2004; Aziz-Zadeh et al., 2009). While the left IFG has been found to be activated in brainstorming (Shah et al., 2011) and DT (Fink et al., 2009; Benedek et al., 2013), the right IFG has been found to be activated in the processing of new metaphors (Mashal et al., 2007). We hypothesized that while a balance in hemispheric activation is needed for DT in general, targeting the IFG in particular will have a stronger effect on verbal DT than on visual figural DT.

Study 1 directly tested the balance hypothesis by either using cathodal stimulation over the left IFG coupled with anodal stimulation the right IFG (Group 1) or by using the opposite montage (Group 2). We expected that within Group 1, stimulation will result in increased creativity on verbal DT tasks compared to sham stimulation, while within Group 2 stimulation will have no effect DT or even diminish levels of verbal DT compared to a sham protocol. Furthermore, we expected that IFG stimulation will affect verbal DT more than visual figural DT. Finally, to examine the bilateral nature of this effect we investigated the effect of cathodal stimulation over the left IFG alone, as well as the effect of right IFG anodal stimulation alone (Study 2). We expected that altering activation over one hemisphere, either by decreasing excitation (cathodal tDCS) over the left IFG or by increasing excitation (anodal tDCS) over the right IFG, would have only a moderate effect on verbal DT or perhaps no effect at all.

## METHODS STUDY 1

### Participants

The participants were all undergraduate native Hebrew speakers from the University of Haifa. All were right handed and had normal or corrected-to-normal vision. All participated in this study as part of an ongoing project to investigate the association between cognitive function and brain stimulation. All the participants who took part in these studies were also administered psychological and cognitive tests that are not part of the current research.

Exclusion criteria included history of seizures or any other neurological disease, heart problems, attention deficit disorder or attention deficit hyperactivity disorder. All participants were naïve to the experimental hypothesis and were unaware of the type of stimulation they received. Participants gave written informed



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