# When Less Is More: Evidence for a Facilitative Cathodal tDCS Effect in Attentional Abilities

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## Abstract

■ Many previous studies reported that the hyperpolarization of cortical neurons following cathodal stimulation (in transcranial direct current stimulation) has resulted in cognitive performance degradation. Here, we challenge this assumption by showing that cathodal stimulation will not always degrade cognitive performance. We used an attentional load paradigm in which irrelevant stimuli are processed only under low but not under high attentional load. Thirty healthy participants were randomly allocated into three interventional groups with different brain stimulation parameters (active anodal posterior parietal cortex [PPC], active cathodal PPC, and sham). Cathodal but not anodal stimulation enabled flanker processing even in high-loaded scenes. A second experiment was carried out to assert whether the improved flanker processing under cathodal stimulation is because of altered attention allocation between center and surround or, alternatively, enhanced attentional resources. In this experiment, the flanker was presented centrally. The results of Experiment 2 replicated Experiment 1's finding of improved flanker processing. We interpret the results from these two experiments as evidence for the ability of cathodal stimulation to enhance attentional resources rather than simply change attention allocation between center and periphery. Cathodal stimulation in high-loaded scenes can act like a noise filter and may in fact enhance cognitive performance. This study contributes to understanding the way the PPC is engaged with attentional functions and explains the cathodal effects, which thus might lead to more efficient brain stimulation protocols. ■

## INTRODUCTION

Transcranial direct current stimulation (tDCS) is a noninvasive method of neuromodulation for the human brain. The method involves attaching two electrodes to the scalp and conducting a weak electrical current from the positively charged cathode to the negatively charged anode. The effects of the different electrodes on brain activity are not fully understood and are still under research. Currently, it is assumed that anodal stimulation enhances the neural firing rate by depolarizing the stimulated area, whereas cathodal stimulation hyperpolarizes cortical neurons in the stimulated area (Bindman, Lippold, & Redfearn, 1964). A recent human imaging study has shown that regional CBF is increased after anodal stimulation and decreased after cathodal stimulation (Zheng, Alsop, & Schlaug, 2011).

Anodal and cathodal stimulation to the motor cortex were shown to respectively enhance or degrade motor evoked potentials (Nitsche & Paulus, 2000). On the basis of these findings, tDCS effects of enhancing anodal and inhibiting cathodal patterns were expected also in the cognitive domain. Although there is much evidence supporting the facilitative effect of the anode (Hsu et al., 2011; Floel, Rosser, Michka, Knecht, & Breitenstein, 2008; Boggio et al., 2007; Fregni et al., 2005), the cathodal effects are less consistently documented in the cognitive domain (Jacobson, Koslowsky, & Lavidor, 2011). Although there is some support for the classical effects of cathodal stimulation (Hsu et al., 2011; Ladeira et al., 2011), there are some studies that have reported a null effect (Fregni et al., 2005) or even an opposite one (Dockery, Hueckel-Weng, Birbaumer, & Plewnia, 2009; Antal et al., 2004).

Antal et al. (2004) stimulated the V5 before, during, or after completion of a motion detection task. Surprisingly, the authors found that the percentage of coherently moving dots needed for correct identification was decreased during and after cathodal stimulation compared with baseline. Hence, cathodal stimulation acted as a facilitator for the task performance. Anodal stimulation had no effect on performance. In a second task, the frame was composed only of coherently moving dots, and participants had to indicate their movement direction. In this task, accuracy was significantly reduced during and immediately after cathodal stimulation, whereas it increased during and immediately after anodal stimulation.

The authors explain this surprising facilitative cathodal effect by assuming that, in complex perceptual tasks, there are competing neural activations corresponding to the different movement directions of the dots. As the percentage of dots moving in a specific direction increases, the corresponding activation for this direction increases as well.

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Cathodal stimulation decreases global neural activity; thus, weak activations from competing directions can be pushed under activation threshold. Although activation from the correct direction is also decreased, there are less-competing answering possibilities. In this way, cathodal stimulation can help decision making in a noisy perceptual environment. In the condition where there were only coherent movement dots, there were no competing directions; therefore, cathodal stimulation was not facilitative, but anodal stimulation enhanced performance, as predicted.

In another study, participants had to complete the tower of London task that measures planning ability (Dockery et al., 2009). Participants completed the task with fewer trials if their dorsolateral pFC was stimulated by the cathode in the early phase of learning. Anodal stimulation improved performance only if it was preceded by cathodal stimulation in the early phase. The authors suggest that cathodal stimulation helps in focusing on the correct response by decreasing global neural activity and diminishing competing activation below threshold.

In the current study, we hypothesized that, under specific conditions of competition between stimuli, cathodal stimulation can act as a noise filter and help perform cognitive tasks. The studies discussed above are examples of situations that involve competition between neural activities, which can be reduced by cathodal stimulation. To test this idea a priori, we used the attentional load paradigm, which is a well-established paradigm of competition between stimuli (Lavie, 2005).

According to the attentional load theory, our attention capacity is limited (Lavie, 1995). In scenes where there is a high perceptual load, one is not able to process all the stimuli, except for those attended. If the scene is less loaded, spared processing abilities will automatically process even irrelevant stimuli (Lavie, 1995). These behavioral evidences for the attentional load theory are supported by imaging data that demonstrate how neural activity corresponding to the irrelevant stimuli decreased as attentional load increased (Schwartz et al., 2005; Rees, Frith, & Lavie, 1997).

In the current study, participants performed the paradigm during anodal or cathodal stimulation of the posterior parietal cortex (PPC), as this area is known to be sensitive to changes in attentional load (Culham, Cavanagh, & Kanwisher, 2001) and is engaged in a variety of attentional functions (Behrmann, Geng, & Shomstein, 2004). Specifically, the PPC is involved in selective attention by receiving information both from the visual cortex and higher frontal areas regarding current task demands (Yantis, 2008). There is evidence of topographic organization of spatial attention signals in the PPC that enables top–down regulation of the visual cortex, according to the task demands (Silver, Ress, & Heeger, 2005). Indeed, cell recording studies (Saalmann, Pigarev, & Vidyasagar, 2007), imaging studies (Bressler, Tang, Sylvester, Shulman, & Corbetta, 2008), and causal TMS studies (Ruff et al., 2009) strengthen this assumption by demonstrating that PPC activity regulates visual cortex activity according to the task demands. Lesions to the PPC induce difficulties in ignoring irrelevant distractors (Friedman-Hill, Robertson, Desimone, & Ungerleider, 2003).

Here, we asked participants to indicate the appearance of a target letter from competing letters and instructed them to ignore flankers (Lavie & Cox, 1997). The flankers could be compatible or incompatible with the target letter. In the low-load condition, we expected interference of the flanker with participants' responses. Participants were expected to respond more quickly when the flanker was compatible with the target, compared with the condition where the flanker was incompatible with the target. This response pattern was not expected to be affected by the stimulation because of the high competition level between stimuli. According to the attentional load theory, in the high-load condition, the flanker should not interfere with the response because of the limited processing capacity (Lavie, 2005). We predicted that cathodal stimulation to the right PPC would minimize the activation from the competing stimuli hence would create a flanker effect in the high-load condition. In other words, participants would respond more quickly when the flanker was compatible with the target.

## EXPERIMENT 1

### Measures and Tools

#### *Participants*

Thirty healthy participants were recruited (20 women). The age range was 18–48 years ($M$ = 26.5 years, $SD$ = 5.9 years). Participants had an average of 14 years of education. These participants were randomly allocated into three interventional groups with different brain stimulation parameters (active anodal PPC, active cathodal PPC, and sham). Mean age and years of education did not differ between the three experimental groups (mean age: anodal group, 27 years; cathodal group, 26 years; sham group, 26 years). Participants were paid 40 NIS for their participation. One participant from the sham group was excluded from further analysis as he did not process the flanker even in the low-load condition. Participants gave a written informed consent before taking part in the study, which was approved by the local institutional review board committee. The participants did not suffer from neurological or psychiatric disorders as well as chronic headaches, were free of medicine, and were not pregnant.

#### *Procedure*

Each session began with 15 min of stimulation in one of the tDCS conditions. Participants completed the attentional load task during the stimulation period.

### Stimuli

We used the flanker task paradigm described elsewhere (Lavie & Cox, 1997). Participants searched for two possible target letters (“X” or “N”) among central nontarget letters (L, M, W, Z, V). Participants had to indicate whether one of the letters was “X” or “N” by pressing a mouse button. Buttons were counterbalanced between participants. Attentional load was manipulated randomly between trials. In the low-load condition, the circle was composed of the target letter with no competing central letters (low competition condition). In the high-load condition, the circle was composed of the target letter and five additional competing letters (high competition condition). A flanker appeared to the right or left of the circle in equal probabilities. The flankers were X or N and could be compatible with the target letter or not (see Figure 1). Participants were instructed to ignore the flankers. The task was applied with the E-prime version 1.1 software (Psychology Software Tools, Pittsburgh, PA) on a computer CRT monitor (34 cm × 27 cm). The distance between the participant and the monitor was 57 cm. The central letters were in Miriam fixed font, 22 points in white. The flanker letters were light gray, 26 points. Letters were presented in uppercase. Circle letters subtended 0.9° vertically and 0.6° horizontally. The flanker subtended 1.1° vertically and 0.9° horizontally. The distance from fixation to the circle subtended 2.1°, and from fixation to the flanker, 4.3°. Stable viewing was supported by a chin rest. Target position (1 to 6), target identity, and distractor compatibility were counterbalanced when the trials were constructed. Trial presentation was randomized within blocks. Each experiment had 192 trials divided into two blocks of 96 trials each.

Each trial in the attentional load task began with 1000 msec of a central white fixation cross. The stimulus was presented for 100 msec. A blank response screen was presented until response or for 2000 msec. A response after 2000 msec was encoded as incorrect. A blank screen was presented for 1000 msec for the intertrial interval.

### Brain Stimulation

Direct current was transferred by a saline-soaked pair of surface sponge electrodes (7 × 5 cm and 4 × 4 cm) and delivered by a specially developed, battery-driven, constant current stimulator (Magstim, Carmathenshire, UK). To focus the stimulation effects, the stimulating electrode was smaller than the reference electrode (Nitsche et al., 2007). To stimulate the PPC, the smaller electrode was placed over P4 according to the 10–20 International system for EEG electrode placement. This method of PPC localization has been used before in tDCS studies (Bolognini, Olgiati, Rossetti, & Maravita, 2010). The other electrode was placed over the contralateral supraorbital forehead. In the anodal stimulation condition, the anode was on the P4, and the cathode, on the supraorbital forehead, and vice versa in the cathodal stimulation condition. Half of the participants in the sham condition had the same electrode montage as in the anodal condition, and the other half, as in the cathodal condition. A constant current of 1.5-mA intensity was applied for 15 min. Participants felt the current as an itching sensation at both electrodes at the beginning of the stimulation. For sham stimulation, the stimulator was turned off after 30 sec. Therefore, the participants felt the initial itching sensation in the beginning but received no current for the rest of the stimulation period. This

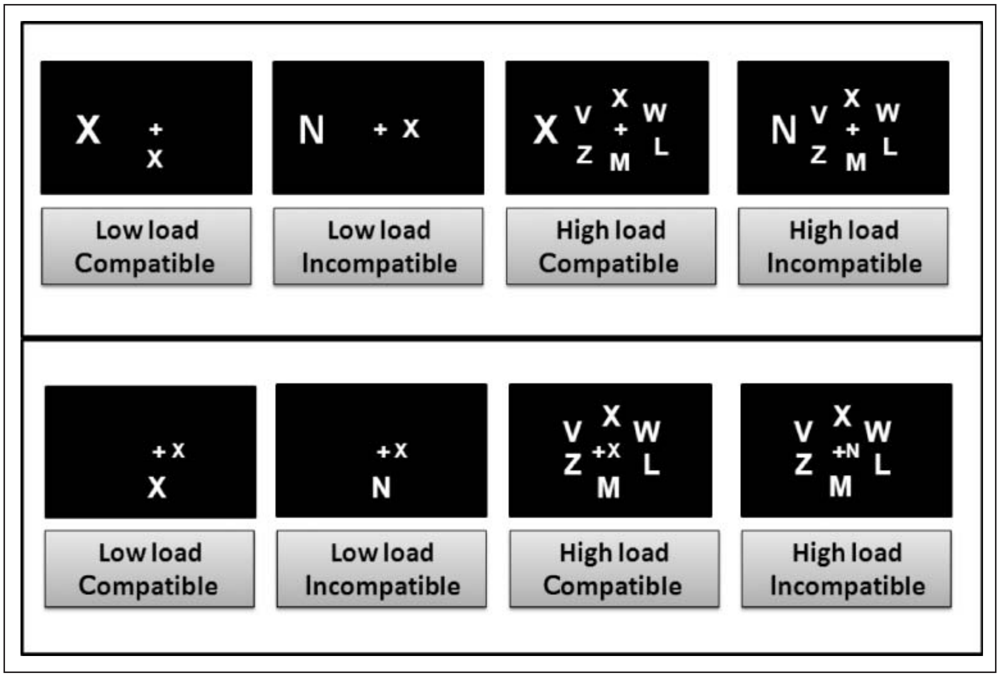

**Figure 1.** Examples of the four within-subject conditions in the attentional load paradigm. Participants were instructed to indicate which one of the two target letters (X or N) was presented in a specific range around the fixation point. The target letter could be presented alone (in the low-load condition) or with other five distracting letters (in the high-load condition). Participants were instructed to ignore flankers, which could be compatible or incompatible with the target letter. The flankers were presented peripherally in Experiment 1 (A) or centrally in Experiment 2 (B).

procedure allowed us to blind participants for the respective stimulation condition (Gandiga, Hummel, & Cohen, 2006).

## Calculations and Statistics

A 2 × 2 × 3 mixed ANOVA with Load (high/low) and Compatibility (incompatible/compatible) as the within-subject factors and Stimulation (anodal/cathodal/sham) as the between-subject factor was conducted. Post hoc Bonferroni tests, corrected for multiple comparisons, were conducted to identify source of significant effects and interactions where relevant.

The flanker effect was calculated to measure flanker intervention with the central task processing. The mean difference in response times between incompatible and compatible conditions was calculated separately for the two load levels for each stimulation group.

## Results

The analysis revealed a main effect of Load ($F(1, 27) = 306.53$, $p < .0001$). Accuracy rates were higher in the low-load condition (89%) compared with the high-load condition (67%; see Table 1A). No additional main effects or interactions of accuracy rates were revealed. Repeated-measures analysis of the mean correct response times revealed a main effect of Load ($F(1, 26) = 122.01$, $p < .0001$). Participants responded more slowly in the higher load condition ($M = 1052$ msec) than in the low-load condition ($M = 806$ msec; see Table 1B). In addition, a main effect of Compatibility was revealed ($F(1, 26) = 15.25$, $p < .001$). Participants responded more slowly in the incompatible condition than in the compatible condition. An interaction between load and compatibility was also found ($F(1, 26) = 9.24$, $p < .005$). Participants responded more slowly to low load with an incompatible flanker. Although it might look at first glance that the anodal group responded faster in the high-load condition compared with the sham and cathodal groups, no interaction between stimulation and load was found ($F(2, 26) = 0.224$, $p = .801$). Crucially, the analysis revealed a three-way interaction between Load, Compatibility, and Stimulation ($F(2, 26) = 4.157$, $p < .027$). To further investigate the source of the interaction, post hoc Bonferroni tests were conducted. Under low load, a significant difference was revealed between the compatible and incompatible conditions (i.e., compatibility effect) in all the stimulation groups (sham: $t(8) = 3.35$, $p < .010$; anodal: $t(9) = 2.61$, $p = .028$; cathodal: $t(9) = 3.50$, $p < .007$). Under high load, no such difference was revealed in the sham group and in the anodal group ($p > .05$ for both groups). However, a significant compatibility effect was found only in the cathodal stimulation group ($t(9) = 4.28$, $p < .002$).

The flanker effect was calculated to demonstrate the flanker interference with response. Repeated-measures analysis revealed a main Load effect ($F(1, 26) = 9.236$, $p < .006$) and an interaction between Load and Stimulation ($F(2, 26) = 4.157$, $p < .027$; see Figure 2). Post hoc Bonferroni tests revealed that the source of the interaction is the significantly bigger compatibility effect, which was found only for cathodal stimulation in the high-load condition. More specifically, under high load, the flanker effect in the cathodal group (mean = 54 msec) was significantly bigger than the anodal flanker effect (mean = 13 msec, $t(18) = 4.6$, $p < .001$) and the sham flanker effect (mean = −8 msec, $t(18) = 5.72$, $p < .0004$). Under low load, flanker effects in all stimulation conditions were similar.

## Discussion

As expected, the accuracy rates were higher in the low-load than in the high-load condition. This finding indicates that the load paradigm did work according to the well-supported theory (Lavie, 2005). Because it was harder to

**Table 1.** Experiment 1: Accuracy Rates and Response Times

| | *Low Load* | | *High Load* | |
|---|---|---|---|---|
| *Condition* | *Compatible* | *Incompatible* | *Compatible* | *Incompatible* |
| *A. Accuracy rates as a function of stimulation condition, attentional load, and distractor compatibility (±SEM)* | | | | |
| Anode | 0.92 (0.02) | 0.90 (0.02) | 0.67 (0.03) | 0.65 (0.03) |
| Cathode | 0.89 (0.03) | 0.86 (0.04) | 0.65 (0.02) | 0.69 (0.03) |
| Sham | 0.93 (0.02) | 0.86 (0.04) | 0.66 (0.04) | 0.68 (0.03) |
| *B. Response times (in msec) as a function of stimulation condition, attentional load, and distractor compatibility (±SEM)* | | | | |
| Anode | 760 (33) | 815 (39) | 1006 (33) | 1020 (43) |
| Cathode | 791 (49) | 837 (49) | 1038 (50) | 1091 (52) |
| Sham | 780 (49) | 865 (61) | 1088 (41) | 1080 (35) |

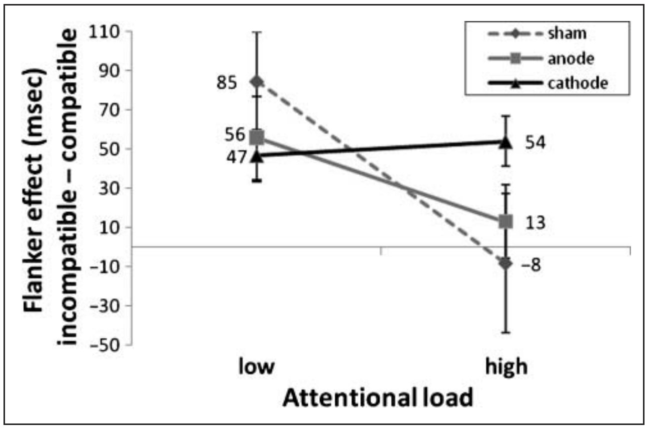

**Figure 2.** The flanker effect in Experiment 1. For each of the load conditions, the mean difference response time between incompatible and compatible conditions was calculated (*SEM*). In the low-load condition, a flanker effect was evident across all groups. However, in the high-load condition, a flanker effect emerged only in the cathodal but not in the anodal or sham stimulation groups.

process all letters in the high-load scene, participants may not have even noticed the correct target letter during the short time span in which the stimuli were presented. The main effects of Load and Compatibility found are also in accordance with previous studies (Lavie, 1995, 2005), as is the two-way interaction between these factors. Participants responded more slowly in the high-load condition because they were occupied with the competing letters in the vicinity of the target. In addition, participants responded more slowly in the incompatible than the compatible condition but only under low-load condition. According to the attentional load theory, attentional resources are limited (Lavie, 1995, 2005); therefore, in the high-load condition, irrelevant or extraneous stimuli (whether compatible or incompatible) would not be processed. In the low-load condition, there were sufficient resources to process both the target letter and the flanker. Spared attentional resources were automatically spilled to process the flanker, although it was not relevant to the task. In the high-load condition, there were not enough resources to process the central circle with the six letters and the flanker. As a consequence, attentional resources were focused on the circle area, where the target was most likely to appear, and the flanker did not interfere with the response.

The novelty in our findings is that we show that this well-documented pattern of response was evident both in the sham and in the anodal but not in the cathodal stimulation group. Crucially, the response pattern of the cathodal stimulation group was significantly different from the pattern described above. Although participants in this group demonstrated a flanker effect in the low-load condition, as expected, the flanker effect was also evident in the high-load condition. This implies that participants in the cathodal group did process the flanker even in the high-load condition. One possible explanation of this observation is that cathodal stimulation enhanced attentional resources' capacity. Enlarged attentional capacity might have enabled processing of both the central letters and the flanker.

Attentional capacity is not constant and can change as a factor of alertness, developmental level, and training (Lavie, 2005). For example, active video game playing was shown to enlarge attentional capacity (Green & Bavelier, 2003, 2006). The authors used an attentional load paradigm, similar to the one used in the current study. Active video game players (VGPs) processed the flanker even under high-load conditions. The authors explain that the VGPs had developed superior attentional load capacity, as a consequence of the training in an environment that requires quick tracking of multiple stimuli. The response pattern of the cathodal group in the current study resembles that of the VGPs group in Green and Bavelier's studies (2003, 2006). Considering this similarity, we interpret results of Experiment 1 as evidence for the ability of cathodal stimulation to enhance attentional resources.

However, there is another possible explanation for the enhanced processing of the peripheral flanker. The observation described above could reflect an alternative attention allocation in the cathodal group, between the center and the periphery. For example, Proksch and Bavelier (2002) found that the attentional capacity of deaf individuals was enhanced in the periphery. However, when a flanker was presented centrally, no enhanced attentional capacity of the deaf participants was evident. The authors suggested an alternative attention gradient in the deaf; in healthy participants, however, the attention is enhanced in the center and declines as moving away to the periphery, deaf participants show the opposite pattern.

To determine which of the two explanations is more plausible, the paradigm used in Experiment 2 was similar to that used in Experiment 1, except that, this time, the flanker was presented centrally to the target letters, not peripherally (Proksch & Bavelier, 2002). This design can assert whether the superior attentional abilities of the cathodal group found in Experiment 1 are restricted to the periphery or whether they are valid at a variety of eccentricities and therefore can be seen as an enlargement of attentional capacity (Proksch & Bavelier, 2002).

## EXPERIMENT 2

### Methods

*Participants*

Twenty healthy naive participants were recruited (nine women). The age range was 19–36 years ($M = 26.7$ years, $SD = 4.3$ years). Inclusion criteria were identical to those described in Experiment 1. Participants had an average of 14 years of education. Because the anodal group in the first experiment did not significantly differ from the sham group, we exclude the anodal condition in Experiment 2.

The participants were randomly allocated into two interventional groups with different brain stimulation parameters (active cathodal PPC and sham). Mean age and years of education did not differ between the two experimental groups (mean age: cathodal group, 26 years; sham, 27 years).

### *Stimuli*

We used the same flanker task described in Experiment 1, except that the flanker was presented centrally and not peripherally. The flanker subtended 0.5° vertically and 0.5° horizontally. The distance from the circle to the flanker subtended 0.5°.

## Results

One participant from the active stimulation group was excluded from further analysis because of technical difficulties. A 2 × 2 × 2 mixed ANOVA with Load (high/low) and Compatibility (incompatible/compatible) as the within-subject factors and Stimulation (sham/cathodal) as the between-subject factor revealed a significant Load effect ($F(1, 17) = 103.142, p < .0001$). Accuracy rates were higher in the low-load (94%) than in the high-load (74%) condition. No other effects or interaction of accuracy rates were identified (see Table 2A).

Only correct answers were chosen for the response times analysis. Extreme results shorter than 300 msec and longer than 1800 msec, a total of 0.4% of all results, were excluded from further analysis. Repeated-measures analysis of participants' correct response times revealed a main effect of Load ($F(1, 17) = 164.735, p < .0001$). Participants responded more slowly in the high-load ($M$ = 965 msec) than in the low-load ($M$ = 717 msec) condition. In addition, a main effect of Compatibility was revealed ($F(1, 17) = 13.916, p < .002$). Participants responded more slowly in the incompatible compared with the compatible condition. An interaction between Load and Compatibility was also evident ($F(1, 17) = 7.210, p < .016$). Participants responded more slowly in the low-load condition with an incompatible flanker. Crucially, the analysis revealed a three-way interaction between Load, Compatibility, and Stimulation ($F(1, 17) = 5.414, p < .033$).

To further investigate the source of the interaction, post hoc Bonferroni tests, corrected for multiple comparisons, were conducted. For low load, a significant difference was revealed between compatible and incompatible conditions in the stimulation groups (sham: $t(9) = -4.870, p < .001$; cathodal: $t(8) = -3.448, p < .009$). Under high load, no such difference was revealed in the sham group ($p > .05$). However, as in Experiment 1, a significant difference between compatible and incompatible condition, for the high load, was found in the cathodal stimulation group ($t(8) = -2.484, p < .038$).

The flanker effect was calculated to demonstrate the flanker interference with response. Repeated-measures analysis revealed a main Load effect ($F(1, 17) = 7.210, p < .016$) and an interaction between Load and Stimulation ($F(1, 17) = 5.414, p < .033$; see Figure 3). Post hoc Bonferroni tests revealed that the source of the interaction is the significantly bigger compatibility effect, which was found only for cathodal stimulation in the high-load condition. More specifically, under high load, the flanker effect in the cathodal group (mean = 39 msec) was significantly bigger than the sham flanker effect (mean = −21 msec, $t(18) = 6.23, p < .0001$). Under low load, flanker effects in the two stimulation conditions were similar.

To assert whether the cathodal effects were consistent in the two experiments, we searched for a four-way interaction between Load, Compatibility, Stimulation Group, and Flanker Eccentricity. Repeated-measures analysis revealed main effects of Load ($F(35, 1) = 254.604, p < .0001$) and Compatibility ($F(35, 1) = 12.229, p < .001$) as well as a significant interaction between them ($F(35, 1) = 10.286, p < .003$). These results are in accordance with the attentional load theory (Lavie & Cox, 1997; Lavie, 1995). The analysis also revealed a three-way interaction between Load, Compatibility, and Stimulation Group ($F(35, 1) = 9.260, p < .004$), whereas there was

**Table 2.** Experiment 2: Accuracy Rates and Response Times

| | *Low Load* | | *High Load* | |
|---|---|---|---|---|
| *Condition* | *Compatible* | *Incompatible* | *Compatible* | *Incompatible* |
| *A. Accuracy rates as a function of stimulation condition, attentional load, and distractor compatibility (±SEM)* | | | | |
| Cathode | 0.95 (0.02) | 0.92 (0.04) | 0.72 (0.04) | 0.74 (0.04) |
| Sham | 0.95 (0.01) | 0.95 (0.03) | 0.76 (0.04) | 0.75 (0.04) |
| *B. Response times (in msec) as a function of stimulation condition, attentional load, and distractor compatibility (±SEM)* | | | | |
| Cathode | 686 (38) | 730 (41) | 911 (36) | 950 (38) |
| Sham | 702 (36) | 750 (39) | 1009 (34) | 988 (36) |

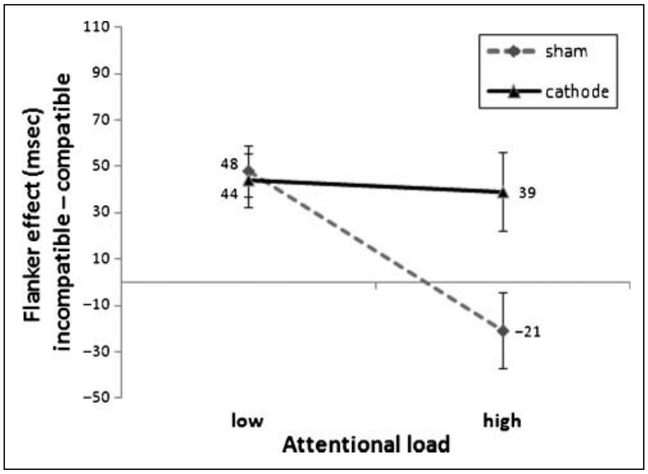

**Figure 3.** The flanker effect in Experiment 2. For each of the two load conditions, the mean difference response time between incompatible and compatible conditions was calculated (*SEM*). In accordance with Experiment 1, although there was a flanker effect in the low-load condition in both stimulation groups, only the cathodal group exhibited a flanker effect in the high-load condition.

no significant four-way interaction between Load, Compatibility, Stimulation Group, and Flanker Eccentricity ($F(35, 1) = 0.176, p > .667$). These results imply that the cathodal effects on the flanker were similar whether the flanker was peripheral or central. There were no other significant effects or interactions.

Analysis of the flanker effect revealed a main effect of load ($F(35, 1) = 10.286, p < .003$). The flanker effect was larger in the low-load condition. An interaction between load and stimulation was also detected ($F(35, 1) = 9.260$, $p < .004$).

## GENERAL DISCUSSION

The results of Experiment 2 replicate those of Experiment 1. The cathodal stimulation group showed a flanker effect in the high-load condition, whether the flanker was presented centrally or peripherally. The flanker effect, which is being used as a measure of attentional capacity (Green & Bavelier, 2003; Proksch & Bavelier, 2002), is the behavioral evidence of the processing of the flanker. According to the attentional load theory, the flanker would automatically be processed if there are spared attentional resources (Lavie, 1995). When the task is demanding, the limited attentional resources would focus on the relevant stimuli and would not process the irrelevant flanker. Indeed, the flanker effect is normally shown under low load but not under high load. However, previous studies reported a flanker effect under high load (Green & Bavelier, 2003, 2006), which resulted from improved attention allocation skills developed at experienced VGPs. By generating a flanker effect under high load with stimulation, the results of the current study support the idea that cathodal stimulation enhances attentional capacity resources. The results do not support the possibility of a trade-off between center and periphery in attentional resources, as superior attentional abilities of the cathodal group were evident both in the periphery and in the center (Proksch & Bavelier, 2002). However, there is a need in a wider research of wider attentional abilities to strengthen the claim of enhanced attentional capacity during cathodal stimulation.

Another possible way for interpreting the results would be that cathodal stimulation prevented the participants from focusing their attention spatially and that they were unable to ignore the distractor outside the focus of attention. Indeed, lesions to the PPC are correlated with difficulties in suppressing intervention from irrelevant distractors (Friedman-Hill et al., 2003). Difficulties in focusing attention are expected to result in a decrease in accuracy level. However, the cathodal stimulation had no effect on accuracy level. This result is in good accordance with claims that cathodal stimulation enabled processing of both the target and the flanker because of enhanced attentional capacity.

The selective cathodal effects might also reflect some increased activation of the left orbital, where the reference (anodal in this case) electrode could increase activity. However, because the effects were polarity dependent and the theoretical background predicted the observed effects in the PPC but not the left orbital cortex, such an alternative account is not very likely. Another possible limitation of the study is related to the double-blind manipulation, which might have been somewhat weaker than the original sham procedure (Gandiga et al., 2006) because of the current density. However, the reported effects did not reflect only polarity effects but were sensitive as well to the attentional load conditions, which therefore cannot be explained simply by awareness to active stimulation conditions.

The current results stand as new evidence supporting the idea that cathodal stimulation effects are variant in the cognitive domain and can sometimes lead to improvement in cognitive performance (Jacobson et al., 2011; Dockery et al., 2009; Antal et al., 2004). These studies involved elements of competition that the cathodal stimulation might have helped to resolve. In the current study, participants were asked to decide which of the two possible target letters was presented. In the high-loaded scene, distracting letters were presented in addition to the target. The distractors' identity was chosen on the basis of common features with the target letters; all were angular letters. The presentation of many distractors made the decision between the two response alternatives more difficult. The cathodal stimulation might have reduced signals from these distractors that were less activated because there was no biased attention toward them. In this way, signals from distractors might be reduced beneath firing threshold. Signals from the target might also be reduced but will benefit from the lower competition, and the signal-to-noise ratio will rise. The cathodal stimulation makes the processing of signals from the center easier, so spared attentional resources are free to process the flanker.

These results support the idea that cathodal effect might be more complex than previously thought. In fact, on certain conditions, cathodal stimulation might enhance cognitive performance. Future studies with tDCS might take into account the unique effects of the stimulation polarity on different tasks.

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