The Impact of Transcranial Direct-Current Stimulation on Self-Control

Dissertation submitted by

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November 2013

as partial fulfilment of the requirements for the Degree of Bachelor of Psychology with Honours in the School of Psychology and Speech Pathology at Curtin University, Western Australia.

Declaration

I declare that this honours dissertation is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information delivered from the published or unpublished works of others has been acknowledged in the text and a list of references is given.

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Ozgur Yalcin

November 08, 2013

Acknowledgements

First and foremost To Lina Cala. It has been an incredibly trying year but we got through it. I could not have made it without your love and support. You are a truly amazing woman. Love you.

To my family, especially you mum. Thank you for all of your love and encouragement throughout my degree. Your support helped me get through the many moments of near insanity.

To my supervisor Dr Andrea Loftus, thank you for your support, I really appreciate all of your brilliant feedback and guidance.

To my lab mates Paul Evens, Hayley Riddle and Emily Corti. Thanks for your support and good times this year. It's been real.

To Dr. Robert Kane, thank you for all your statistical advice and putting up with my impromptu visits during the semester.

To Dr Meghan Thomas, thank you for taking the time out to provide invaluable feedback. I know it is a very busy time of year, and I really appreciate your time.

To my amazing friends, thank you for being there for me this year.

To Hooman and Liz. Thank you for your love, friendship, flexibility and support over the years.

Finally, to the amazing cohort of fellow psychology students. It's been great to get you know you over the years. We made it!

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Abstract

Self-control is the ability to control emotion, cognition and behaviours in order to reach a desired outcome or goal. According to the Strength Model, self-control can be depleted after repeated acts of self-control. Cross-hemispheric transcranial Direct Current Stimulation (tDCS) over the Dorsolateral Prefrontal Cortex (DLPFC) has been previously shown to enhance decision making, task switching and risk evaluation. The current study examined the effects of cross-hemispheric tDCS over the DLPFC on self-control in young adults. In a mixed-design experiment, 43 young adults aged between 18 and 35 were randomly assigned to one of three tDCS groups; anodal right-cathodal left (ALCR), anodal left-cathodal right (ARCL), or sham tDCS. Self-control was assessed based on performance (reaction time) and error on the Stroop colour-word naming task pre and post tDCS. The results indicate that both ALCR, $p = .000$, $d = 1.57$, 95% CI [115.20, 338.64] and ARCL, $p = .001$, $d = .73$, 95% CI [64.82, 208.53] conditions were successful in enhancing participants self-control as quantified by the Stroop task. The findings of this study provide preliminary evidence that modulation of the DLPFC with tDCS can induce changes in self-control behaviour.

Key Words: transcranial Direct Current Stimulation, Dorsolateral Prefrontal Cortex, self-control, Strength Model, Stroop, inhibition, cross-hemispheric.

Many activities require us to exercise self-control such as eating a healthy diet, budgeting, exercising, and not indulging in maladaptive behaviours such as smoking and drinking to excess (Tangney, Baumeister, & Boone, 2004). Research suggests that greater self-control is associated with positive outcomes across a multitude of domains. For example, individuals with higher self-control demonstrate higher self-esteem (Tangney et al., 2004), higher academic performance (Tangney et al., 2004), are more psychologically attuned (Hofmann, Friese, & Strack, 2009), and exhibit less impulsive behaviours such as pathological gambling and substance abuse (Baumeister & Heatherton, 1996). Baumeister and colleagues developed a comprehensive, capacity-based model to examine failures in self-control (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Muraven, Baumeister, & Tice, 1999). This theoretical framework, called the Strength Model, is based on the premise that regulating self-control is dependent on a type of energy or strength (Muraven & Baumeister, 2000).

The Strength Model

The Strength Model suggests that engaging in repeated acts of self-control draws from a single, finite resource that once depleted, reduces an individual's ability to further exert self-control (Muraven & Baumeister, 2000). If an individual does not experience a period of rest after attempting self-control, the resource becomes depleted and self-control failures increase (Baumeister et al., 1998). A popular analogy suggests that self-control operates in a similar way to a muscle, which can be fatigued and depleted following repeated exertion (Muraven & Baumeister, 2000). In an experiment conducted by Baumeister et al. (1998) participants who were asked to eat radishes instead of chocolates (thereby exerting self-control) gave up much earlier on an unsolvable puzzle compared to those participants who did not exert self-control (i.e. those participants who were permitted to eat the chocolates). These findings are supported by several studies of self-control which examine the Strength Model (Baumeister, Vohs, & Tice, 2007; Muraven & Baumeister, 2000; Muraven et al., 1998). A meta-analysis conducted by Hagger, Wood, Stiff, and Chatzisarantis (2010) assessed over 80 papers and concluded that depletion on self-control tasks were widely observed in a number of domains including effort, negative affect, blood glucose levels and perceived difficulty. Results of this study indicate a medium to large effect size (Cohen's d = 0.62; Cohen, 1992) when self-control depletion was measured within the framework of the Strength Model.

Neural Correlates of Self-Control

Neuroimaging has allowed researchers to identify the neural correlates of self-control

by examining neuronal activation or inhibition in areas associated with self-control. A number of studies suggest that Dorsolateral Prefrontal Cortex (DLPFC) is activated by tasks such as decision making and problem solving (Aue, Lavelle, & Cacioppo, 2009); skills which may underlie self-control. DLPFC is also associated with the ability to switch between tasks, modulate numerous aspects of decision making such as the appraisal of uncertainty and risk, as well as self-control (Fecteau, Knoch, et al., 2007; Fernandez-Serrano, Perez-Garcia, Schmidt Rio-Valle, & Verdejo-Garcia, 2010). One task that has been used to measure self-control and cognitive inhibition is the Stroop colour-word naming task (West, 2003). To successfully complete the Stroop task, cognitive inhibition is necessary to supress the automatic tendency to read the word instead of naming the colour it is presented. A functional Magnetic Resonance Imaging (fMRI) study by Friese, Binder, Luechinger, Boesiger, and Rasch (2013) found significantly higher levels of neural activity in DLPFC when participants responded to a computerised version of the Stroop during an emotion suppression task compared to a control group, who did not have to suppress their emotions. Self-control is necessary to not only supress emotion but also to inhibit responses on the Stroop task. The computer version of this task also requires behavioural inhibition as participants need to physically respond to these conflicting stimuli by pushing a button.

Further evidence of the role of DLPFC in self-control is provided by Steinbeis, Bernhardt, and Singer (2012) who examined children's decision making abilities whilst playing two different games involving economic exchange, the Ultimate Game and the Dictator Game. In the Ultimate Game, a proposer and a responder negotiate the division of a set amount of money between them. The proposer can offer a split of the sum, which the responder either accepts or rejects. In the case of acceptance, the money is shared between the players. If however the responder rejects the proposal, neither player gets money. Thus, the proposer needs to exercise self-control and act strategically when making their offer. The Dictator Game differs in that the responder can only accept an offer made by the proposer. fMRI results demonstrated significant neural activity in left DLPFC when participants were required to exert self-control, that is, when children played the proposer in the Ultimate Game. This finding is consistent with other studies demonstrating the activation of DLPFC in tasks involving self-control (Glascher, Hampton, & O'Doherty, 2009; Hare, Camerer, & Rangel, 2009; MacDonald, Cohen, Stenger, & Carter, 2000). Although fMRI can provide valuable insight in to brain behaviour, it is limited in that it cannot allow researchers to modulate neuronal activity in areas of interest. Other methods of investigation may be needed

to address further examine the role of DLPFC in self-control.

Non-Invasive Brain Stimulation

Non-invasive brain stimulation such as transcranial Direct Current Stimulation (tDCS) is a painless, non-invasive and inexpensive method used to modulate neural activity (Nitsche et al., 2008). tDCS allows researchers to examine the impact of exciting or inhibiting neuronal activation on behaviour (Fecteau, Pascual-Leone, et al., 2007). The process involves the application of two surface electrodes, an anode and cathode, which are placed on the scalp to create a direct current that penetrates the underlying cortical area and modulates the rate of firing of individual neurons (Been, Ngo, Miller, & Fitzgerald, 2007). This weak, constant current, can either increase or decrease cortical excitability, depending on the intensity and direction of the current. Cathodal tDCS has an inhibitory effect by hyperpolarising neurons and anodal tDCS has an excitatory effect by depolarising neurons in the underlying cortex. Gandiga, Hummel, and Cohen (2006) suggest that tDCS is safe and provides a reliable control (sham) condition. During sham tDCS, the direct current is initiated for 30 seconds and subsequently switched off. Participants thus feel the initial tingling sensation associated with tDCS but without changes in cortical excitability. Leite, Carvalho, Fregni, Boggio, and Goncalves (2012) examined the effects of contralateral tDCS on DLPFC on task switching. Sixteen participants completed two visual cue switch tasks with similar stimulus response mappings but with differing cognitive demand. The first task (letter/digit naming task) required participants to respond to a letter or a number following either a red or green visual cue. The second task (vowel-consonant parity task) was more demanding, with participants required to make a judgement and respond according to both visual colour cues as well as conflicting semantic information (vowel or consonant). Reaction time and accuracy rates were recorded for each participant. Participants were assigned to one of three conditions (i) Anodal over left DLFFC/ Cathodal over right DLPFC (ALCR), (ii) Cathodal over left DLPFC/Anodal over right DLPFC (ARCL), or (iii) Sham tDCS. Participants in the experimental conditions received tDCS with a 2mA current for 3 minutes prior to commencing the tasks. For the letter/digit naming task, ALCR improved task switching performance and ARCL improved accuracy. In contrast, ALCR improved accuracy but decreased switching performance in the vowel-consonant/parity task. Taken together, these results suggest that the impact of tDCS is task and hemisphere specific. The results also suggest that the left and right hemispheres of DLPFC adopt different strategies when it comes to information processing.

The effect of tDCS over DLPFC has also been examined during a risky decision

making task using the Balloon Analogue Risk Task (BART; Fecteau et al., 2007). Participants were presented with a balloon and had a chance to earn money by pumping it up with a click of a button. With every click the balloon was inflated, increasing the amount of money deposited into a temporary bank, but also increased the chance of the balloon exploding. When the participants stopped pumping, the accumulated money was transferred to a permanent bank, however if the balloon burst, the accumulated money was lost (Fecteau et al., 2007). Participants received ALCR, ARCL, or sham tDCS. Participants in the experimental groups received tDCS with a 2mA current for 5 minutes before and during the task. tDCS, regardless of the configuration, was found to significantly decrease the incidence of risky decisions compared to sham. Furthermore, participants in the experimental groups demonstrated more cautious decision making (indicated by less money in the bank) compared to sham. These findings suggest that contralateral tDCS of DLPFC (i.e., across two hemispheres) effects decision making when it comes to risk averse or risk taking decisions (Fecteau et al., 2007).

The Current Study

Using the Stroop colour-word naming task, the current study will examine whether exciting or inhibiting DLPFC with contralateral tDCS impacts upon self-control in young adults. The present study also sought to test the Strength Model of self-control by investigating whether depletion in self-control would be observed after two consecutive self-control tasks. Given that tDCS enhances planning (Dockery, Hueckel-Weng, Birbaumer, & Plewnia, 2009), task switching (Leite et al., 2012) and risk taking behaviours (Fecteau et al., 2007), it is reasonable to suggest that tDCS of the DLPFC may enhance self-control in healthy young adults. Based on the findings reviewed above, the following hypotheses are proposed:

H1. For anodal tDCS over left DLPFC and cathodal tDCS over right DLPFC (ALCR) there will be a significant pre-post decrease in reaction time in conjunction with significant pre-post decrease in error on the Stroop task compared to sham tDCS.

H2. For anodal tDCS over right DLPFC and cathodal tDCS over left DLPFC (ARCL) there will be a significant pre-post increase in reaction time in conjunction with significant pre-post increase in error on the Stroop task compared to sham tDCS.

H3. Sham tDCS will lead to no change in reaction time or error on the Stroop task.

Method

Research Design

This study employed a mixed factorial design with tDCS condition (anodal left,

anodal right, sham) as a between subjects factor and time (pre, post) as a within subjects factor. Participants were randomly allocated to one level of tDCS and were blind to which condition they were in. To control for individual differences, pre and post testing of each participant was conducted to reduce error variance.

Participants

Prior to data collection, power calculations using G-Power (Faul, Erdfelder, Lang, & Buchner, 2007) indicated that in order to achieve the desired power of .80 at an alpha level of .05 and a moderate (.40) effect size, 42 participants (14 in each group) were required. A convenience sampling strategy was used to recruit fourty three adults. The sample consisted of second year psychology students who were recruited from the Curtin University participant pool, other psychology students, and via the online social media site Facebook. The sample comprised 15 males (34.9%) and 28 females (65.1%). The age of the participants ranged from 18 to 35 years (M=24.5, SD=4.7). Participants from Curtin University participation pool were awarded participation points for taking part in the study. A Facebook page was set up containing the information sheet and exclusion criteria to recruit members of the non-Curtin population**.** Members of the non-Curtin population went into a draw to win a $100 department store gift card for their participation.

Measures

Transcranial Direct Current Stimulation (tDCS). The Soterix™ 1x1 system was used to deliver a 2mA (equivalent to 0.08 Ma/CM2) current between a pair of 5 x 7 cm saline soaked sponge electrodes. The use of large electrodes ensures that current density is well below levels that might be perceived as unpleasant or painful. tDCS is generally administered for between 3-20 minutes. tDCS was administered for 10 minutes. Additional tDCS information is provided in the procedures section.

Stroop Self Control Measure. The Stroop colour-word naming task (Baughman, 2013) assesses the ability to direct attention and inhibit irrelevant material. If a word is displayed in a colour different from the colour it actually names (for example, the word black written in yellow ink- incongrunent), participants take longer to name the word than if the word is displayed in a colour the same as the word (for example, the word green written in green ink- neutral). Self-control is necessary to inhibit the automatic tendency to read the word instead of naming the colour it is presented in. Previous research has validated the use of Stroop as a measure of self-control (Baumeister et al., 2007).

Hard Counting Task. A hard counting task involves counting in a sequence that is considered difficult, such as counting down from 2000 in multiples of 7 (2000, 1993,

1986…). Previous studies (Tyler & Burns, 2008; Webb & Sheeran, 2003) have validated the use of a hard counting task as a reliable measure to induce self-control depletion.

Procedure

Ethics approval was obtained from the Curtin University Human Research Ethics Committee. Upon arrival at the Neuroscience laboratory, the researcher went over the exclusion criteria and information sheet with the participant. The exclusion criteria ensured that participants were suitable candidates for tDCS and were in accord with safety guidelines (Nitsche et al., 2008). After informed consent was obtained, participants were asked to complete a test of self-control before and after tDCS.

Participants first completed a computerised, online version of the Stroop colour–word naming task (Baughman, 2013) as a measure of self-control. Participants were instructed that two words would be simultaneously presented on the screen, one at the top and one at the bottom, with the top word appearing in one of four colours (yellow, red, blue, and green) and the bottom word appearing in grey. They were asked to decide, as quickly and as accurately as possible, whether the colours on the word on the top, matched the meaning of the word on the bottom. Participants responded by clicking the left mouse button for a ‘match’ response and the right mouse button for a ‘non-match’ response. Before each test trial, participants completed a practice trial which comprised seven stimulus presentations. This was followed by 64 test trials which comprised 32 neutral and 32 incongruent trials. Neutral trials were presented as a random set of letters (e.g., NSGL) and incongruent trials were real words that were different both in colour and semantics (e.g., the word BLUE in the colour red). Trials were counterbalanced and randomly presented across each condition. Stimuli remained on the screen until a response was given, or until five seconds had passed, followed by a fixation cross. Each test took approximately 10 minutes to complete, and reaction time and error rates were recorded for each test stimulus. Following this, participants completed the tDCS part of the study.

Participants were randomly assigned to one of three tDCS conditions: anodal stimulation, cathodal stimulation or sham. ALCR was performed with the anode placed above the left DLPFC (F3 using the 10-20 system) and the cathode placed above the contralateral right DLPFC (F4 using the 10-20 system). For ARCL, the montage was reversed such that the cathode was above the left DLPFC and the anode above the contralateral right DLPFC. Sham stimulation was conducted with the same montage as in the anodal stimulation, with 30 seconds of tDCS applied at onset, after which the current stimulator was de-ramped. tDCS was administered for 10 minutes, during which time the

participant watched a short video.

Following tDCS, participants completed the hard counting task. Participants were asked to stand on their non-dominant leg whilst counting down from 2000 in multiples of seven (2000, 1993, 1986….). The addition of a physical task (standing on one leg) to the maths task has been to shown to exaserbate self-control depletion (Tyler & Burns, 2008; Webb & Sheeran, 2003). This task took five minutes to complete. Participants then completed the same Stroop task as for pre tDCS. Upon finishing the study, participants were debriefed and thanked for their time.

Results

Data Screening

Prior to analysis the data was screened for outliers. No univariate outliers were detected from this data.

Assumptions

For the dependent variable reaction time, Shapiro-Wilk indicated that the data were not normally distributed (p = < .05), however skewness and kurtosis statistics were within ± 1.96 (Tabacknick and Fidell, 2013), except for pre-test incongruent reaction time in the ALCR condition (skewness = -1.611, kurtosis = 4.34). Analysis of Variance (ANOVA) is considered a robust statistical test, despite these violations.

For the dependent variable error, the Shapiro-Wilk statistics indicated that the data were not normally distributed. Skewness and kurtosis exceeded 1.96 for a number of conditions. Given non-parametric tests have problems handling interactions in factorial designs (Rodriguez, Alvarez, & Remirez, 2009), Tabacknick and Fidell (2013) suggest applying square root transformations to normalise the dependent variable. This was applied to the dependent variable error, after which the data were normally distributed.

ANOVA Results

A 2 x 3 Mixed Analysis of Variance (ANOVA) with tDCS condition (ALCR, ARCL, SHAM) as between groups factor and time (pre, post) as within groups factor revealed a significant main effect of time for reaction time, F (1, 40) = 52.73, p =.000, partial $\eta^2 = .57$. Post-tDCS reaction times across all conditions (M = 891.1, SD = 185.1) was significantly faster than pre-tDCS reaction time (M = 1042.54, SD = 183.1), regardless of trial type. There was also a significant main effect of time for error, F (1, 40) = 22.47, p =.000, partial $\eta^2 = .36$. Participants made less errors across all post-tDCS conditions (M = .77, SD= .68) compared to pre tDCS (M = 1.3, SD = .8), regardless of trial type.

There was a significant main effect of trial type for reaction time, F (1, 40) = 110.8, p

=.000, partial η^2=.735. Neutral trials were faster (*M* = 886.9, *SD* = 167.1) than incongruent trials (*M* = 1047.7, *SD* = 201.1), regardless of time and condition. Participants also made less errors for neutral (*M* = .631, *SD* = .73) than incongruent trials (*M* = 1.44, *SD* = .76) regardless of time and condition. These main effects are indicative of the Stroop effect in that participants generally take longer and make more errors on incongruent trials of the Stroop compared to neutral or congruent trials (West, 2003).

There was a significant Time x Condition interaction for reaction time, *F* (2, 40) = 3.59, *p* =.037, partial η^2 =.152. There was no Time x Condition interaction for error, *F* (2, 40) = 3.59, *p* =.33, partial η^2 =.053. To examine the reaction time interaction, Bonferroni-adjusted pairwise comparisons were used to compare pre-tDCS and post-tDCS reaction times across each condition for each trial type separately. To avoid type one errors, an adjusted alpha level of .008 (.05/6) was applied. There was a significant effect of time for reaction time in the neutral ALCR condition, *t* (13) = 7.32, *p* = .000, two tailed, *d* = 1.83, 95% CI [148.55, 272.85]. This was a very large effect. There was no pre-post significant difference for neutral trials in the sham or ARCL condition, *p*'s > .008. There was no pre-post significant difference for incongruent trials in the sham condition, *p* > .008.There was a significant effect of time for reaction time in the incongruent ALCR condition, *t* (13) = 5.82, *p* = .000, two tailed, *d* = 1.57, 95% CI [115.20, 338.64] and for incongruent ARCL condition, *t* (13) = 4.12, *p* = .001, two tailed, *d* = .73, 95% CI [64.82, 208.53], both indicating very large effects. In summary pre-post reaction time for neutral and incongruent trials in ALCR and incongruent trials in ARCL conditions were significantly faster than both pre-post neutral and incongruent trials of sham. See Table 1 for means and standard deviations.

There was a significant Time x Trial Type interaction for reaction time, *F* (1, 40) = 7.79, *p* =.008, partial η^2 =.163, but no such interaction for error, *F* (1, 40) = 2.00, *p* =.165, partial η^2= .048. To examine this interaction, Bonferroni-adjusted pairwise comparisons were used to compare pre-tDCS and post-tDCS differences across each condition. To avoid type one errors, an alpha level of .025 (.05/2) was applied. There was a significant effect of time and trial type for pre-tDCS reaction time, *t* (42) = -9.81, *p* = .000, two tailed, *d* = 1.00, 95% CI [-222.43, -146.50], and post-tDCS reaction time, *t* (42) = -8.98, *p* = .000, two tailed, *d* = .75, 95% CI [-169.41, -107.25] tDCS. This indicates that reaction time improved in both pre-tDCS and post-tDCS across all conditions, regardless of trial type. See table 1 for means and standard deviations. There was no interaction between time, trial type and condition for either reaction time *F* (2, 40) = .569, *p* =.570, partial η^2=.028, or error *F* (2, 40) = 1.11, *p* =.339, partial η^2 =.053.

Table 1
Means and Standard Deviations of Reaction Time and Transformed Error for Trial Type, Time and Condition on Stroop Colour-Word Naming Task.

	Neutral				Incongruent			
	Pre-tDCS		Post-tDCS		Pre-tDCS		Post-tDCS	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
ALCR-RT	982.88*	124.62	772.20*	160.71	1153.70*	153.40	906.78*	160.70
ARCL-RT	994.30	202.22	838.40	145.42	1103.12*	218.54	966.44*	156.46
SHAM-RT	925.51	164.86	858.35	228.54	1146.65	232.81	1009.75	261.64
ALCR-ER	.462	.680	.476	.670	1.74	.757	1.17	.780
ARCL-ER	1.03	1.04	.469	.675	1.92	.696	1.24	.750
SHAM-ER	.986	.775	.360	.537	1.61	.810	.971	.794

Note: * $p < .008$, ALCR-RT= anodal left/cathodal right reaction time, ARCL-RT = anodal right/cathodal left reaction time, SHAM-RT = sham reaction time. ALCR-ER = anodal left/cathodal right error, ARCL-ER= anodal right/cathodal left error, SHAM-ER= sham error

Discussion

The purpose of this study was to examine whether modulating neuronal activity in DLPFC with contralateral tDCS would impact upon self-control in young adults. We also examined the Strength Model hypothesis and investigate whether self-control depletion would be observed after two self-control tasks. Our results partially supported the hypothesis that ALCR tDCS would result in decreased reaction time and fewer errors on the second Stroop task. The hypothesis that ARCL tDCS would result in increased reaction time and increased error on the second Stroop task was not supported. The hypothesis that there would be no difference in reaction time and error between on Stroop performance pre and post tDCS in the sham condition was not supported.

We anticipated that participants in the ALCR group would have faster reaction time and make fewer errors post-tDCS. In this study, participants significantly improved on reaction time performance when left DLPFC was activated by anodal (excitatory) tDCS and right DLPFC with cathodal (inhibitory) tDCS. Participants also made fewer errors, however this difference was not statistically significant across conditions. These findings are in line with previous tDCS studies which have shown increased performance in a number of domains when neuronal activity in left DPLFC has been stimulated by anodal (excitatory) tDCS (Dockery et al., 2009; Leite et al., 2012).

We anticipated that modulating left DLPFC with cathodal tDCS and right DLPFC with anodal tDCS would increase reaction time and increase error post-tDCS, indicating that participants are less likely to exert self-control in this condition. Contrary to predictions, the results indicate that participants significantly improved their performance for reaction time. Participants also made fewer errors post tDCS, however this difference was not statistically significant. One reason for this result may be the contralateral application of tDCS across DLPFC. Previous tDCS research has shown that when tDCS is applied unilaterally (i.e., on one hemisphere) with the other electrode placed on the contralateral supraorbital, tDCS was ineffective in producing changes in task performance. Fecteau et al. (2007) found that unilateral tDCS was not effective in inducing changes in a risky decision making task, however when tDCS was applied cross hemispherically, participants in this study changed to a more risk averse decision making style regardless of the montage of tDCS (i.e., anodal left/cathodal right and vice versa). Our results are in line with Fecteau et al. (2007) in that, regardless of the montage, participants were better at inhibiting automatic responses and responded more efficiently to conflicting stimuli (incongruent trials).

In the ARCL condition, reaction time was significantly faster in the incongruent, but not neutral trials of Stroop compared to sham tDCS. This result is unusual as neutral trials of Stroop are typically performed significantly faster compared to incongruent trials (West, 2003). Leite et al. (2012) found similar results when cross hemispheric tDCS resulted in unexpected outcomes in a task switching paradigm. This may suggest that the left and right hemispheres of DLPFC adopt different strategies when it comes to self-control processes (Leite et al., 2012). Although the current study cannot determine the exact underlying mechanisms that contributed to the enhanced performance for reaction time in both experimental conditions, it could be that stimulating DLPFC with tDCS may have induced changes in neural plasticity such that long term potentiation could occur (Nitsche et al., 2008). Long term potentiation is an increase in synaptic strength which results in long-lasting transmission between two neurons (Luscher & Malenka, 2012). Significantly faster reaction times in both ALCR and ARCL groups compared to sham tDCS may have been observed due to this increase in synaptic strength and amplified communication between neurons (Luscher & Malenka, 2012).

We anticipated that that there would be no difference in Stroop performance in pre and post sham tDCS. According to the Strength Model, participants should perform worse on a third self-control measure after two unrelated self-control tasks. Our results do not provide support for this hypothesis as participants recorded faster reaction times and made less errors post sham tDCS compared to pre sham tDCS. One reason for this non-significant finding could be the 10 minutes of ‘rest’ participants had between the first and second self-control task in the sham condition. This may have replenished their self-control resource such that the hard counting task was not sufficient to further deplete self-control after the initial Stroop task (Baumeister et al., 1998). Given the speculative nature of this argument, future research may shed some light on the effects of task and temporal ordering, and measurement choice within the Strength Model paradigm (Hagger, Wood, Stiff, & Chatzisarantis, 2009).

The present study had a number of limitations. Firstly, this study cannot conclusively establish whether the effects were due only to anodal stimulation or cathodal stimulation or if they are due to the anodal-cathodal interaction. In addition, we cannot dismiss the possibility that modulating the targeted DLPFC with tDCS did not impact on other densely connected areas of Prefrontal Cortex such as Ventromedial Prefrontal Cortex, an area which is also implicated in self-control (Hare et al., 2009). This said, the effects of tDCS may not have been powerful enough to reached Anterior Cingulate Cortex,

a sub cortical area responsible for conflict and error detection (Fuster, 2008). This may explain our non-significant findings in error across conditions. Future research may benefit from using neuroimaging to investigate which neural changes are associated with neural modulation and the impact on subsequent behaviour (Hedgcock, Vohs, & Rao, 2012). The convenience sample of mostly university students in this study makes it difficult to translate our findings to the general population. Furthermore, experiments conducted in a controlled laboratory environment may limit the applicability of these findings to real world situations.

Despite these limitations, this investigation represents a unique and important contribution to the literature on self-control regulation. This is the first study that has investigated the effects of tDCS on self-control. Secondly, this study included a sample larger than most previously conducted research in tDCS. Thirdly, the counterbalancing of neutral and incongruent trials of the Stroop across all conditions may have prevented participants from developing strategies to enhance performance on the second Stroop task. Because of the short time (15 minutes) between Stroop tasks, it would be reasonable to expect practice effects to confound our results. A between groups design was intentionally used to address this issue. Although improvements were evident across all conditions, the results of our study clearly indicated that participants in the experimental conditions showed significant improvements in reaction time compared to sham, particularly on incongruent trials, which require additional cognitive resources to inhibit irrelevant material (West, 2003). Another strength is the reliability of sham tDCS to provide an excellent control condition (Gandiga et al., 2006). Sham stimulation emits a brief current at the beginning and then switches off for the remainder of the stimulation time, thus participants are unaware that they are not receiving prolonged stimulation (Gandiga et al., 2006). At the end of the experiment, all participants reported not knowing which condition they were in. This added to the robustness of our study as we were able to confidently conclude that our results were obtained through our manipulation and not from potentially confounding variables such as expectancy effects.

Findings from the present study show that it may be feasible to assume that modulating neuronal activity may strengthen self-control processes in humans. A number of preliminary studies have found positive, real world benefits of tDCS. Fregni et al. (2008) found that smokers experienced a reduced number of nicotine cravings after cross hemispheric tDCS over both DLPFC’s. Additionally, the contralateral application of tDCS was successful in decreasing cravings for people with alcohol dependence (Boggio et al.,

2008). Given the results of these studies, one may speculate that the therapeutic benefits of tDCS may be of use to those people who have trouble with self-regulation and poor impulse control such as pathological gamblers, particularly if tDCS does induce changes in neural plasticity and increase synaptic strength. Future research could further investigate the impact of tDCS on these neurobiological mechanisms of self-control.

In conclusion, this study investigated the impact of tDCS on self-control in young adults. The findings of this study provide preliminary evidence that modulation of the DLPFC with tDCS can induce changes in self-control behaviour. Future studies are needed to investigate the neural correlates of self-control and their interaction with different aspects of cognition such as decision making and problem solving. This study enhances our knowledge of tDCS and further highlights the importance of continued research into tDCS and self-control.

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Extended Literature Review

As humans, we have the unique ability to plan ahead and engage in goal directed behaviour to not only reach desired outcomes but to function optimally in society (Tangney, Baumeister, & Boone, 2004). Many activities require us to exercise self-control such as eating a healthy diet, budgeting, exercising, and not indulging in maladaptive behaviours such as smoking and drinking to excess (Tangney et al., 2004). Research suggests that increased self-control is associated with positive outcomes across a number of domains. For example, individuals with a higher capacity for self-control have higher self-esteem (Tangney et al., 2004), exhibit higher academic performance (Tangney et al., 2004) and are more psychologically attuned (Hofmann, Friese, & Strack, 2009). In contrast, people who have trouble regulating self-control may experience numerous social and personal problems such as poor dietary intake, risk taking behaviours (Hagger, Wood, Stiff, & Chatzisarantis, 2009), and may exhibit more impulsive behaviours such as pathological gambling or substance abuse (Baumeister & Heatherton, 1996). Baumeister and colleagues (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Muraven, Baumeister, & Tice, 1999; Muraven, Tice, & Baumeister, 1998) developed a capacity-based model to explain why failures in self-control occur. This theoretical framework, called the Strength Model, is based under the premise that regulating self-control is dependent on a kind of energy or strength (Muraven & Baumeister, 2000).

Strength Model

The Strength Model suggests that engaging in repeated acts of self-control draws from a single, finite resource that once depleted, reduces an individual's ability to further exert self-control (Muraven & Baumeister, 2000). If an individual does not experience a period of rest after attempting self-control, the resource becomes depleted and self-control failures increase (Baumeister et al., 1998). A popular analogy suggests that self-control operates in a similar way to a muscle, which can be fatigued and depleted following repeated exertion (Muraven & Baumeister, 2000). Comparable to this, exerting self-control may consume self-control strength, whereby reducing the amount of strength available for subsequent self-control attempts (Muraven & Baumeister, 2000).

Dual task paradigms are commonly used when testing self-control depletion in the Strength Model (Muraven et al., 1998). In a typical dual task experiment, an experimental group are required to engage in two self-control tasks. Participants in the control group are also required to engage in two tasks, however only the second task requires self-control. In line with the Strength Model, the experimental group should show a significant decrease in self-control in task two compared those in the control group, as they would have drawn on

their self-control 'reservoir' during task one (Hagger, Wood, Stiff, & Chatzisarantis, 2010). In an experiment conducted by Baumeister et al. (1998) participants who were asked to eat radishes instead of chocolates (thereby exerting self-control) gave up much earlier on an unsolvable geometric puzzle compared to those participants who did not exert self-control (i.e. those participants who were permitted to eat the chocolates). These findings are supported by several studies of self-control which examine the Strength Model (Baumeister, Vohs, & Tice, 2007; Muraven & Baumeister, 2000; Muraven et al., 1998; Tangney et al., 2004). A subsequent study by Baumeister et al. (1998) found that participants who were required to suppress their emotion (show no emotion whilst watching an evocative video) had significantly impaired performance on a grip strength task compared with those that did not have to suppress their emotions.

A meta-analysis conducted by Hagger et al. (2010) assessed over 80 papers and concluded that depletion on self-control tasks were widely observed in a number of domains including effort, negative affect, blood glucose levels and perceived difficulty. Results of this study indicate a medium to large effect size (Cohen's $d = 0.62$; Cohen, 1992) when self-control depletion was measured within the framework of the Strength Model. Although the behavioural consequences of self-control depletion have been well documented (Baumeister et al., 1998; Baumeister et al., 2007; Muraven et al., 1999; Muraven et al., 1998), the mechanisms that account for these effects are less understood (Hedgcock, Vohs, & Rao, 2012) therefore other methods, such as neuroimaging, may shed more light on the mechanics of self-control.

Neural Correlates of Self-Control

Neuroimaging has allowed researchers to identify the neural correlates of self-control by examining neuronal activation or inhibition in areas associated with self-control. A number of studies show that ventromedial Prefrontal Cortex, Anterior Cingulate Cortex and Dorsolateral Prefrontal Cortex (DLPFC) are implicated in self-control functioning (Hare, Camerer, & Rangel, 2009; Heatherton, 2011; Krug & Carter, 2010). Significant neural activity has been shown in Anterior Cingulate Cortex in response to conflicting stimuli and error detection, such as in the incongruent trials is the Stroop task (West, 2003) or when individuals are faced with situations where self-control is needed, such as refraining from eating unhealthy snacks when attempting to lose weight (Hedgcock et al., 2012). Research shows that goal directed decisions have their basis in value signals encoded in the ventromedial Prefrontal Cortex. This suggests that the value that is attributed to a given stimuli plays a significant role in a person's decision making

processes (Heatherton, 2011). Furthermore, the Ventromedial Prefrontal Cortex has been implicated in cognitive inhibition and consequences of future actions (George & Koob, 2013). The DLPFC is implicated in the regulation of complex emotional, cognitive, and behavioural functioning and is associated with integrating and controlling input from other frontostriatal regions such as Anterior Cingulate Cortex and Ventromedial Prefrontal Cortex (Fuster, 2008; George & Koob, 2013; Hofmann, Schmeichel, & Baddeley, 2012). The DLPFC is also associated with the ability to switch between tasks (Leite, Carvalho, Fregni, Boggio, and Goncalves, 2012), modulate numerous aspects of decision making such as the appraisal of uncertainty and risk (Fecteau, Knoch, et al., 2007), as well as self-control (Fernandez-Serrano, Perez-Garcia, Schmidt Rio-Valle, & Verdejo-Garcia, 2010).

One task that has been used to measure self-control and cognitive inhibition is the Stroop colour-word naming task (Stroop, 1935). The Stroop task assesses the ability to direct attention and inhibit irrelevant material, both aspects associated with self-control (MacLeod, 1991) . If a word is displayed in a color different from the color it actually names (for example, the word black written in yellow ink- incongrunent), participants take longer to name the word than if the word and colour is the same (for example, green written in green ink- neutral). Self-control is necessary to inhibit the automatic tendency to read the word instead of naming the colour it is presented in (West, 2003). A functional Magnetic Resonance Imaging (fMRI) study by Friese, Binder, Luechinger, Boesiger, and Rasch (2013) found significantly higher levels of neural activity in DLPFC when participants responded to a computerised version of the Stroop task during an emotion suppression task compared to a control group, who did not have to suppress their emotions. Self-control is necessary to not only supress emotion, but also to inhibit automatic responses on the Stroop task. The computer version of this task also requires behavioural inhibition as participants need to physically respond to these conflicting stimuli by pushing a button.

Further evidence of the role of DLPFC in self-control is provided by Steinbeis, Bernhardt, and Singer (2012) who examined children’s decision making abilities whilst playing two different games involving economic exchange, the Ultimate Game and the Dictator Game. In the Ultimate Game, a proposer and a responder negotiate the division of a set amount of money between them. The proposer can offer a split of the sum, which the responder either accepts or rejects. In the case of acceptance, the money is divided between the players; however, if the responder rejects the proposal, neither player gets money. Thus, the proposer needs to exercise self-control and act strategically when

making their offer. The Dictator Game differs in that the responder can only accept an offer made by the proposer. fMRI results demonstrated significant neural activity in left DLPFC when participants were required to exert self-control, that is, when children played the proposer in the Ultimate Game. This finding is consistent with other studies demonstrating the activation of DLPFC in tasks involving self-control (Glascher, Hampton, & O'Doherty, 2009; Hare et al., 2009; MacDonald, Cohen, Stenger, & Carter, 2000).

Supporting these findings, and providing evidence for the Strength Model and self-control depletion is a study by Hedgcock et al. (2012). In this study, fMRI was performed whilst participants engaged in two unrelated tests of self-control. The initial test required participants to hold their attention on a fixation cross and ignore words that randomly flashed on the screen. The second task involved choosing preferred items from a list of options. Previous research has shown self-control depletion when participants were made to choose an option from a number of similar pairs of items (Wang, Novemsky, Dhar, & Baumeister, 2010). Results showed neural activity in the Anterior Cingulate Cortex and DLPFC during the first and second task, however participants displayed less activity in DLPFC when they performed the second self-control task, i.e. when their self-control had been depleted. This was one of the first studies that investigated the Strength Model using neuroimaging techniques and provides some preliminary neurophysiological evidence for the self-control depletion hypothesis. fMRI can provide valuable insight in to brain behaviour, however it is limited in that it cannot allow researchers to modulate neuronal activity in areas of interest; hence other methods of investigation may be needed to further examine the role of DLPFC in self-control.

Non-Invasive Brain Stimulation

Non-invasive brain stimulation such as transcranial Direct Current Stimulation (tDCS) is a painless, non-invasive and inexpensive method used to modulate neural activity (Nitsche et al., 2008). tDCS allow researchers to examine the impact of exciting or inhibiting brain activation on behaviour (Fecteau, Knoch, et al., 2007). The process involves the application of two surface electrodes, anode and cathode, which are placed on the scalp to create a direct current that penetrates the underlying cortical area and modulates the rate of firing of individual neurons (Been, Ngo, Miller, & Fitzgerald, 2007). This weak, constant current, leads to either increased or decreased cortical excitability depending on the intensity and direction of the current. Cathodal tDCS typically has an inhibitory effect by hyperpolarising the neurons and anodal tDCS has an excitatory effect

by depolarising neurons in the local cerebral cortex. Gandiga, Hummel, and Cohen (2006) found that tDCS is safe and provides a reliable control (sham) condition. During sham tDCS, the direct current is initiated for 30 seconds and subsequently switched off. Participants thus feel the initial tingling sensation associated with tDCS but without changes in cortical excitability.

Leite, Carvalho, Fregni, Boggio, and Goncalves (2012) examined the effects of cross hemispheric tDCS on DLPFC on task switching. Sixteen participants completed two visual cue switch tasks with similar stimulus response mappings but with differing cognitive demand. The first task (letter/digit naming task) required participants to respond to a letter or a number following either a red or green visual cue. The second task (vowel-consonant parity task) was more demanding in that participants were required to make a judgement and respond according to both visual colour cues as well as conflicting semantic information (vowel or consonant). Reaction time and accuracy rates were recorded for each participant. Participants were assigned to one of three conditions (i) Anodal over left DLFFC/ Cathodal over right DLPFC (ALCR), (ii) Cathodal over left DLPFC/Anodal over right DLPFC (ARCL), or (iii) Sham tDCS. Participants in the experimental conditions received tDCS with a 2mA current for 3 minutes prior to commencing the tasks. For the letter/digit naming task, ALCR improved task switching performance and ARCL improved accuracy. In contrast, ALCR improved accuracy but decreased switching performance in the vowel-consonant/parity task. Taken together, these results suggest that the impact of tDCS is task and hemisphere specific. The results also suggest that the left and right hemispheres of DLPFC adopt different strategies when it comes to information processing.

In support of these findings, Dockery, Hueckel-Weng, Birbaumer, and Plewnia (2009) examined the effects of tDCS on planning ability using the Tower of London task (TOL). In the minimum number of moves, participants were required to rearrange a set of three coloured balls on pegs, so the final configuration matches a specific goal state. Twenty four healthy adults received 15 minutes of anodal, cathodal or sham tDCS over left DLPFC while performing TOL and were measured on reaction time and accuracy (number of moves) over three sessions in a one week period. Results indicated both anodal and cathodal tDCS over left DLPFC was effective in enhancing planning ability as indicated by faster task completion and more accuracy compared to sham.

The effect of tDCS over DLPFC has also been examined during a risky decision making task using the Balloon Analogue Risk Task (BART; Fecteau et al., 2007).

Participants were presented with a balloon and had a chance to earn money by pumping it up with a click of a button. With every click the balloon was inflated, increasing the amount of money deposited into a temporary bank, but also increased the chance of the balloon exploding. When the participants stopped pumping, the accumulated money was transferred to a permanent bank, however if the balloon burst, all of the money accumulated was lost (Fecteau et al. 2007). Participants received ALCR, ARCL, or sham tDCS. Participants in the experimental groups received tDCS with a 2mA current for 5 minutes before and during the task. tDCS, regardless of the configuration, was found to significantly decrease the incidence of risky decisions compared to sham. Furthermore, participants in the experimental groups demonstrated more cautious decision making (indicated by less money in the bank) compared to sham. These findings suggest that contralateral tDCS of DLPFC (i.e., across two hemispheres) effects decision making when it comes to risk averse or risk taking decisions (Fecteau et al., 2007).

The Current Study

Using the Stroop colour-word naming task, the current study will examine whether exciting or inhibiting DLPFC with contralateral tDCS impacts upon self-control in young adults. The present study also seeks to test the Strength Model of self-control by investigating whether depletion in self-control would be observed after two consecutive unrelated self-control tasks. Given that tDCS enhances planning (Dockery et al., 2009), task switching (Leite, Carvalho, Fregni, Boggio, & Goncalves, 2012) and risk taking behaviours (Fecteau, Pascual-Leone, et al., 2007), it is reasonable to suggest that tDCS of the DLPFC may enhance self-control in healthy young adults. Based on the findings reviewed above, the following hypotheses are proposed:

H1. For anodal tDCS over left DLPFC and cathodal tDCS over right DLPFC (ALCR) there will be a significant pre-post decrease in reaction time in conjunction with significant pre-post decrease in error on the Stroop task compared to sham tDCS.

H2. For anodal tDCS over right DLPFC and cathodal tDCS over left DLPFC (ARCL) there will be a significant pre-post increase in reaction time in conjunction with significant pre-post increase in error on the Stroop task compared to sham tDCS.

H3. Sham tDCS will lead to no change in reaction time or error on the Stroop task.

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Supplementary Material

Supplementary Material A: Ethics Approval Letter

Curtin University

Memorandum

To	Dr Andrea Loftus, Psychology and Speech Pathology
From	Professor Stephan Millett, Chair, Human Research Ethics Committee
Subject	Protocol Approval **HR 32/2013**
Date	6 March 2013
Copy	

Office of Research and Development
Human Research Ethics Committee

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for providing the additional information for the project titled "*The Impact of transcranial direct current stimulation on executive functioning*". The information you have provided has satisfactorily addressed the queries raised by the Committee. Your application is now **approved**.

- You have ethics clearance to undertake the research as stated in your proposal.
- The approval number for your project is **HR 32/2013.** *Please quote this number in any future correspondence.*
- Approval of this project is for a period of four years **01-03-2013** to **01-03-2017**.
- Your approval has the following conditions:
  i) Annual progress reports on the project must be submitted to the Ethics Office.
  ii) Registration as a clinical trial.
  Chapter 3.3 of the National Statement on Ethical Conduct in Human Research states:
  A clinical trial is a form of human research designed to find out the effects of an intervention.
- **It is your responsibility, as the researcher, to meet the conditions outlined above and to retain the necessary records demonstrating that these have been completed.**

Applicants should note the following:

It is the policy of the HREC to conduct random audits on a percentage of approved projects. These audits may be conducted at any time after the project starts. In cases where the HREC considers that there may be a risk of adverse events, or where participants may be especially vulnerable, the HREC may request the chief investigator to provide an outcomes report, including information on follow-up of participants.

The attached **FORM B** should be completed and returned to the Secretary, HREC, C/- Office of Research & Development:
When the project has finished, or

- If at any time changes/amendments occur, or
- If a serious or unexpected adverse event occurs.

Yours sincerely

Professor Stephan Millett
Chair Human Research Ethics Committee

Supplementary Material B: Participant Information Sheet

PARTICIPANT INFORMATION SHEET

Project title: The Impact of Non-Invasive Brain Stimulation on Self Control

Ethics approval reference: HR32/2013

Invitation

You are invited to participate in a research project investigating whether transcranial Direct Current Stimulation (tDCS) impacts upon self-control (the ability control our emotions, cognitions and behaviours). tDCS is a safe non-invasive brain stimulation technique which delivers low electrical currents through electrodes placed on the scalp. Please take time to read the following information carefully. Ask us any questions if some part of the information is not clear to you or if you would like more information. Please ask any questions you have before you sign the consent form.

Who is the Chief Investigator of this study?

Dr Andrea Loftus, School of Psychology & Speech Pathology, Curtin University, (08) 9226 2308. The researcher is Ozgur Yalcin, School of Psychology & Speech Pathology, Curtin University, 0499 621 760.

Why have I been invited to participate in this research?

You have been invited to participate in this study as you are between the ages of 18 and 35 and have met the requirements for participation. You may decide to be in the study or not take part at all. If you do decide to take part in this study, you may stop at any time. However, before you decide, it is important that you understand why this research is being done and what it will involve. The following information will explain the study and assist you to decide whether or not to participate.

What are the aims of this study?

A number of recent studies have shown that non-invasive brain stimulation techniques may result in improvements in memory, learning and thinking. One such method is transcranial Direct Current Stimulation (tDCS). This method stimulates the brain via an electrode on the scalp that transmits a weak direct current. tDCS is non-invasive and painless and is established as a safe method of brain stimulation.

This study investigates whether tDCS can be used to promote change in self-control. Self-control refers to the ability to control our emotions, cognitions and behaviours by frequently regulating impulses and temptations. Eating a healthy diet, budgeting and exercising are all examples of self-control. If tDCS is found to impact upon self-control, it could help our understanding of how self-control can be improved and may contribute to interventions for those with difficulties regulating their self-control

How long will I be in this study?

If you decide to participate in the study you will be asked to visit the School of Psychology at Curtin University for about one hour.

What is transcranial Direct Current Stimulation (tDCS) and how does it work?
The human brain is made up of billions of tiny neurons and electrical currents. All our actions and thoughts are dependent upon the firing and inhibition of these neurons. tDCS is the application of weak electrical currents (1-2 mA) to change the electrical activity of these neurons. tDCS works by altering the firing rates of the neurons. When the tDCS electrodes are placed on the scalp, the electrical change produced in the brain is exceedingly small, changing neuron excitability by only a fraction of a millivolt. The use of tDCS has not been associated with any adverse outcomes.

What will happen if I decide to be in this study?
If you decide to be a part of this study, the researcher will ask you some general medical questions to determine if you are suitable for tDCS. This can be done over the telephone or upon your arrival at the University if you prefer. If you are an online participant, please read the exclusion criteria below and email Ozgur Yalcin: ozgur.yalcin@student.curtin.edu.au with your name and expression of interest. If you are suitable for tDCS, the researcher will arrange a time that is convenient for you to come to the lab.

On arrival at the lab, the researcher will give an overview of the experiment and what is required of you and will ask whether you have any questions. Should you wish to participate in the study, you will then be invited to provide informed consent for participation. You will then be asked to sit in a comfortable chair for approximately ten minutes.

This study is made up of three parts, all completed within one testing session:

Part 1: Baseline measure of Self Control
You will be asked to sit in a comfortable chair and complete a task that measures of self-control on a computer. No prior computer skills are required to complete these tasks. Before completing the task, verbal instructions and a demonstration will be provided by the researcher. The task will take approximately 5 - 10 minutes.

Part 2: Transcranial Direct Current Stimulation (tDCS):
The researcher will measure and attach two electrodes to your head – one on the front right part of your head and one at the front left part of your head. These will be secured using specially designed headbands which will wrap around your head. tDCS will then be administered for 10 minutes, during which time the researcher will chat with you or, if you prefer, you can read one of our magazines. You will be offered light refreshment during this phase.

Part 3: Post-tDCS Measures of Self Control
You will be asked to complete another task that measures self-control. Before completing the
task, verbal instructions and a demonstration will be provided by the researcher. The task will take approximately 10 minutes during which time the researcher will chat with you or, if you prefer, you can read one of our magazines. You will then complete the same task as you did for part 1.

You can terminate the study at any point without effect or explanation should you wish.

What are the benefits of my participation?
The study may not be of direct benefit to you; however the findings will potentially benefit individuals who have deficits in the ability to regulate their self-control. Your participation will provide us with a clearer understanding of how tDCS can aid in the improvement of self-control in general.

What can go wrong if I take part in this study?
This research project is not expected to pose any risk to you. There have been no long-lasting adverse effects associated with tDCS. The tDCS protocol to be used in this study has been employed by numerous researchers with no reports of subject discomfort or harm. The investigators will strictly adhere to the current international safety guidelines and precautions for the use of tDCS in the study.

Who will have access to my data?
Information which could identify you as an individual will not be published or reported. Only the combined results of all participants in the study will be published or reported. You will remain anonymous as you will only be identified by a code number. The coded data will be securely stored for at least five years, as prescribed by university regulations and will only be accessible to the study investigators.

Who has approved this study and does it meet ethical requirements?
The project will be carried out according to the National Statement on Ethical Conduct in Research Involving Humans (June 1999) produced by the National Health and Medical Research Council of Australia and according to the Good Clinical Practice Guidelines. This research project has been reviewed and approved by the Human Research Ethics Committee of the Curtin University (project number: HR32/2013)

Who can I contact about this study?
If you have any questions or concerns about this study, please contact the Ozgur Yalcin whose contact details are listed at the start of this information sheet.

Do I get to keep a copy of the Information Sheet and Consent form?
You will be given a copy of the Information Sheet to keep. If you decide to take part in this
research you may request a copy of this signed consent form for your records also.

What if there is a problem and I want to make a complaint?
If you have any concerns of an ethical nature or complaints about the manner in which the research is conducted, please contact the Human Research Ethics Committee by telephoning (08) 9266 2784 or emailing hrec@curtin.edu.au. Alternatively, you may write to the Office of Research and Development, Curtin University of Technology, GPO Box U1987, Perth WA
6845).

Supplementary Material C: Exclusion Criteria

Curtin University of Technology

TDCS EXCLUSION CRITERIA

You cannot participate in this research project if you have had any of the following procedures or if any of the following conditions apply to you:

• Any neurological disorder or brain surgery

• Any history of epilepsy

• Currently taking psychoactive medication

• Any active skin disease (such as eczema) on the scalp

• Any unstable medical condition (for example, un-controlled diabetes)

• Any history of migraine

• Any history of episodes of faintness (one isolated incident is not an episode)

• Any history of asthma

• Any metal implants or devices in your body (e.g. surgical clip, coronary stent)
Note: metal dental fillings or metal dental braces will not exclude you from participating.

• Currently using a hearing aid

Please indicate whether any of the above exclusion criteria apply to you
YES [ ]
NO [ ]

Name: _____

Signature: _____

Supplementary Material D: Consent Form

Consent Form

Project: The Impact of Transcranial Direct Current Stimulation on Self Control
Ethics approval number: HR32/2013
Chief Investigator: Dr Andrea Loftus, School of Psychology and Speech Pathology, Curtin University

I (Participant's Name)_____ confirm that:

1. I have understood and completed the tDCS exclusion criteria checklist

2. I have been given clear information (verbal and written) about this study and have been given time to consider whether I want to take part.

3. I have been told about the possible advantages and risks of taking part in the study and I understand what I am being asked to do.

4. I have been able to ask questions about the study and its procedures and all questions have been answered satisfactorily.

5. I know that I do not have to take part in the study and that I can **withdraw at any time** during the study without any effect and without having to explain why.

6. I agree to take part in this research study and for the data obtained to be published provided my name or other identifying information is not used.

If you are unclear about anything you have read in the Information Sheet or this Consent Form, please speak to one of the Investigators before signing this Consent Form.

Name of Participant Signature of Participant

Date_____

This study has been approved under Curtin University's process for research with humans. This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18-5.1.21). For further information on this study contact the researchers named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au.

Supplementary Material E: Script for tDCS Experiment

Firstly I would like to thank you for coming along today and for taking part in this research, I really appreciate your participation. Did you have a chance to read to information sheet and exclusion criteria on line? Was there anything you were unsure of, or any questions you have about the study? If you think of any questions on the way through, please don't hesitate to ask.

The tasks today are designed to be in three parts and should take about an hour to complete.

Firstly, I will ask you some demographic questions and then you will be asked to complete a computer based test of self-control. Then we will move onto the tDCS part of the study. Following this, you will be asked to complete another measure of self-control. Finally you will be required to complete the same computer based task as you did at baseline.

As you may have noticed, I am reading a lot of what I am saying. It is important when doing research that everyone has the same type of experience, so I need to give the instructions the same way every time.

I have a consent form I would like you to sign. Have a read through, and please don't hesitate to ask any questions you may have. Also go through the exclusion criteria

First I would like to ask you some demographic questions (demographic questionnaire).

Age gender, occupation handedness etc..

Great. If you are ready, we will begin the first task.

In this activity, you will see a word appear at the top part of the screen. This word will appear in one of 4 colours. At the bottom part of the screen another word will appear. Your task is to decide as quickly as possible, without making any mistakes, whether the colour of the letters in the word on the top, matches the meaning of the word on the bottom.

You will first be presented with first you will 8 practice goes then the real trials will begin. Left click on the mouse if you think they match and the right click on the mouse if you think they don't match.

Now we will move on to the tDCS part of the study.

Please make yourself comfortable in this chair as I get set up. *Ask the participant if they have any questions.*

Before starting ensure that the pads are soaked in saline and the tDCS machine is set up ready for testing.

Firstly, I am going to take some measurements of your head.

First locate Cz. This is done by firstly measuring the participants head from Nasion (which is the distinctly depressed area between the eyes, just above the bridge of the nose) to the

Inion (which is the lowest part of the skull from the back of the head and is normally indicated by a prominent bump). Divide the distance between these points by two to find Cz. For example if Nasion to Inion is 34cm, then Cz will be 17cm along from either point. Place a small mark on the scalp with a non-toxic marker. Secondly, take measurements from the left auditory bone (A1 on the 10-20 system) to the right auditory bone (A2 on the 10-20 system) and divide the measure by two and mark with a whiteboard marker. This point and the last (Nasion to Inion) will be the location of Cz.

For Hypothesis 1, *the anode electrode will be positioned at F4, a position that can be located by measuring 1.5cm sagittally and 1.5 cm laterally (left) from Cz. Cathode electrode will be positioned at F3, a position that can be located by measuring1.5cm sagittally and 1.5 cm laterally (right) from Cz. Both sets of electrode pads will then be secured in position using a head strap.*

For Hypothesis 2, *the anode electrode will be positioned at F3, a position that can be located by measuring 1.5cm sagittally and 1.5 cm laterally (right) from Cz. Cathode electrode will be positioned at F4, a position that can be located by measuring1.5cm sagittally and 1.5 cm laterally (left) from Cz. Both sets of electrode pads will then be secured in position using a head strap.*

For Sham*, both anode and cathode will be in the same positions as Hypothesis 1, but without stimulation.*

Ok that's great. I will now position the pads with this head strap, please let me know if it is too tight. I will now turn on the tDCS, you may feel a slight tingling when I turn it on, a bit like pins and needles, but that should quickly dissipate.

Make sure the Sotrix system is set up so that the dials are as follows: 2mA, 10 minutes of stimulation, and the 'relax' dial is at full current. Then when everything is ready, start the stimulation by pressing pre stim tickle. After this press the 'start' button and the sotrix system will slowly amp up to 2mA and the countdown timer will start.

Ensure there is good contact between the electrodes and the scalp, at least 75% contact from optimal. You will see this on the Sotrix device.

For sham tDCS, also ensure the 'Sham' switch is on. Initialt tDCS with pre stim tickle. Following this, press the start button. The participant will feel the initial tingling of the tDCS, however this will only last 30 seconds and the Sotrix system will automatically deramp. The Sotrix system will automatically ramp up again when there is 30 seconds remaining to ensure the participant thinks they are receiving tDCS.

Offer the participant refreshments. All participants will watch an episode of Mr Bean whilst receiving stimulation.

Following the completion of tDCS stimulation, the electrodes and head strap will be removed.

Ok how do you feel? Remember you can stop at any time.

The next task involves a bit of mental arithmetic and balance. I will ask you to stand on your non-dominant leg and at the same time count down from 2000 in multiples of

seven. For example, 2000, 1993, 1986 and so on until I ask you to stop. Please be as accurate as you can.

This task will go for 5 minutes.

Ok, you will be asked to complete the same computer task as you did when you first arrived.

Go through the same procedure as the initial Stroop task starting with the practice trials.

Ok, that brings us to the end of the experiment. I will now debrief you on what we did today and the rationale for conducting this research. Feel free to ask any questions.

Debrief

Background:

Many activities require us to exercise self-control such as eating a healthy diet, budgeting, exercising, and not indulging in maladaptive behaviours such as smoking and drinking to excess. Research suggests that increased self-control is associated with positive outcomes across a number of domains. For example, individuals with a higher capacity for self-control have higher self-esteem, exhibit higher academic performance, are more psychologically attuned, and exhibit less impulsive behaviours such as pathological gambling and substance abuse.

Aims:

The aim of this study is to examine whether tDCS on DLPFC impacts upon self-control in healthy young adults. This was be done by measuring self-control before and after a short period of tDCS.

Method:

A convenience sample of 45 healthy individuals was randomly assigned to 3 experimental conditions:

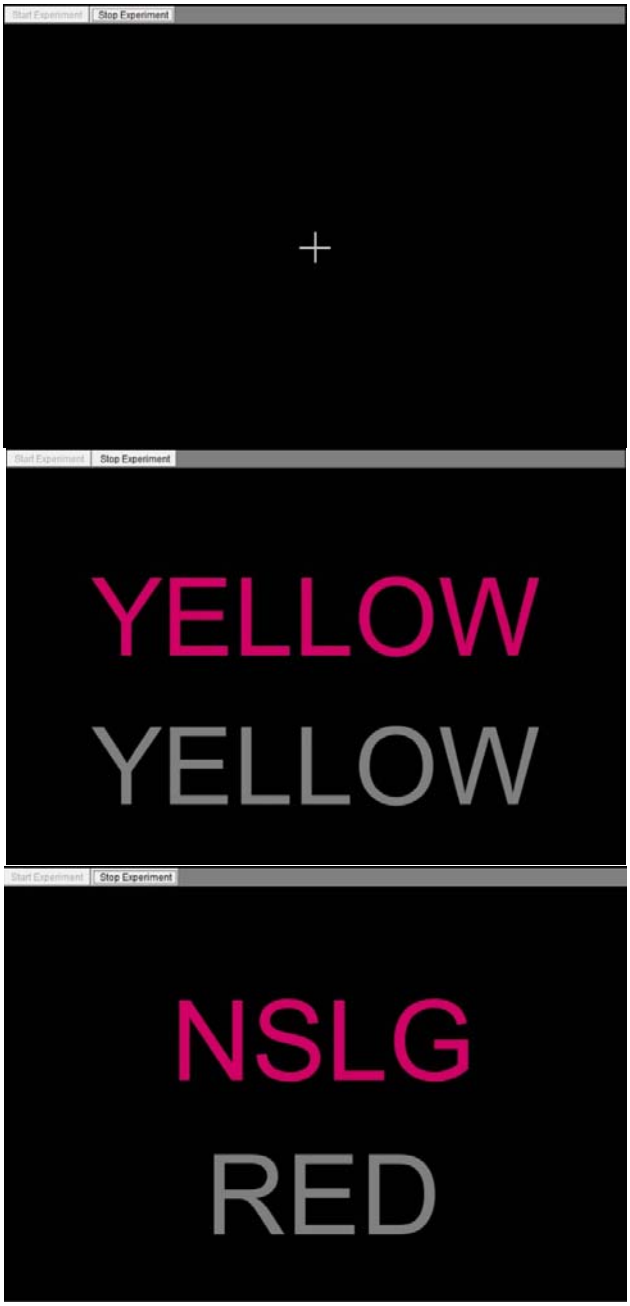
1- Anodal (excitatory tDCS) over the left Dorsolateral Prefrontal Cortex (DLPFC) and Cathodal (inhibitory tDCS) over right DLPFC
2- Cathodal (inhibitory tDCS) over the right Dorsolateral Prefrontal Cortex (DLPFC) and Anodal (excitatory tDCS) over left DLPFC
3- Sham (same as 1 but with no stimulation, i.e., the control group)

Studies have shown that cross hemispheric tDCS have shown improvements on people's ability to make risk adverse decisions and task switching hence the rationale for testing it in this study.

I hypothesised that:

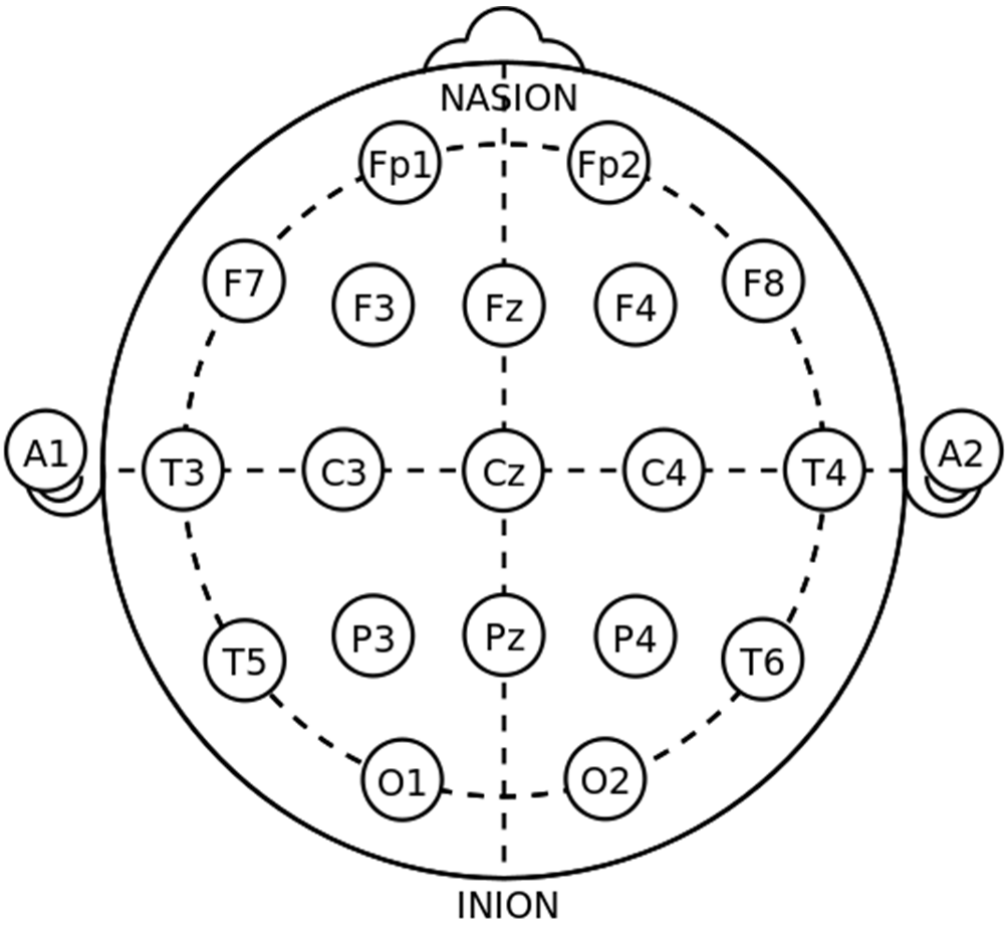
For anodal tDCS over left DLPFC and cathodal tDCS over right DLPFC there will be a significant pre-post decrease in reaction time in conjunction with significant pre-post decrease in error rate on the Stroop task.
For anodal tDCS over right DLPFC and cathodal tDCS over left DLPFC there will be a significant pre-post decrease in reaction time in conjunction with significant pre-post increase in error rate on the Stroop task.
For sham tDCS, pre-post changes in reaction time and error rate will be negligible

Supplementary Material F: Example of the Stroop Colour-Word Naming Task



Note: Stroop conditions. The image in the centre is an incongruent trial because the meaning of the top of the screen interferes with the colour. The image in the centre is a neutral trial because the set of random letters does not interfere with the colour

Supplementary Material G: Electroencephalogram (EEG) 10-20 System



Supplementary Material H: Assumptions Testing for Reaction Time

A 3 x 2 Mixed ANOVA was conducted to test whether there were any differences between reaction time (pre/post) and the experimental conditions (Anodal, Cathodal, Sham). Before running the ANOVA the data was scanned for outliers and the assumptions of scale of measurement, independence, normality, homogeneity of variance, homogeneity of covariance and sphericity were tested (Allen & Bennett, 2010).

Assumption Testing

Outliers. Outliers were defined at a score that is 3.29 standard deviations above or below the mean (Tabacknick & Fidell, 2007). Upon inspection of the statistics, only one case was deemed as an outlier. This case was retained as this experiment requires the pure measure of reaction time pre and post tDCS.

Scale of measurement. The dependant variable (reaction time) provided ratio data; therefore the assumption of scale of measure was met.

Normality. Normality was assessed by inspecting the Shapiro-Wilk statistics, skewness and kurtosis and the relevant histograms. For one of the independent variables the Shapiro-Wilk statistic was significant indicating that the data were not normally distributed. The majority of the skewness and kurtosis statistics were within ± 1.96, except for pre-test incongruent reaction time in the ALCR condition (skewness= -1.611, kurtosis = 4.34).

Homogeneity of variance. The Levene's test for equality of variances for pre-test neutral reaction time was non-significant (F= 2.86, p=.069) indicating that the homogeneity variance was not violated. The homogeneity of variance assumption was also not violated for pre-test incongruent reaction time (F= 2.56, p=.091) or post-test incongruent reaction time (F= 1.71, p=.190). The homogeneity of variance was violated for post-test neutral reaction time (F= 3.37, p=.044). Analysis of Variance (ANOVA) is considered a robust statistical test, despite these violations.

Homogeneity of covariance. Box's M statistic for indicated that the homogeneity of intercorrelations assumption was not violated, p = .139.

Sphericity. Sphericity is assumed as the repeated measures factor (pre/post) has only two levels.

Supplementary Material I: SPSS Output for Reaction Time

Within-Subjects Factors

Measure: REACTION_TIME

TIME_NEUTRAL	TIME_INCON	Dependent Variable
1	1	RT_NEUTRAL_PRE
	2	RT_INCON_PRE
2	1	RT_NEUTRAL_POST
	2	RT_INCON_POST

Between-Subjects Factors

		Value Label	N
CONDITION	1	ALCR	14
	2	ARCL	14
	3	SHAM	15

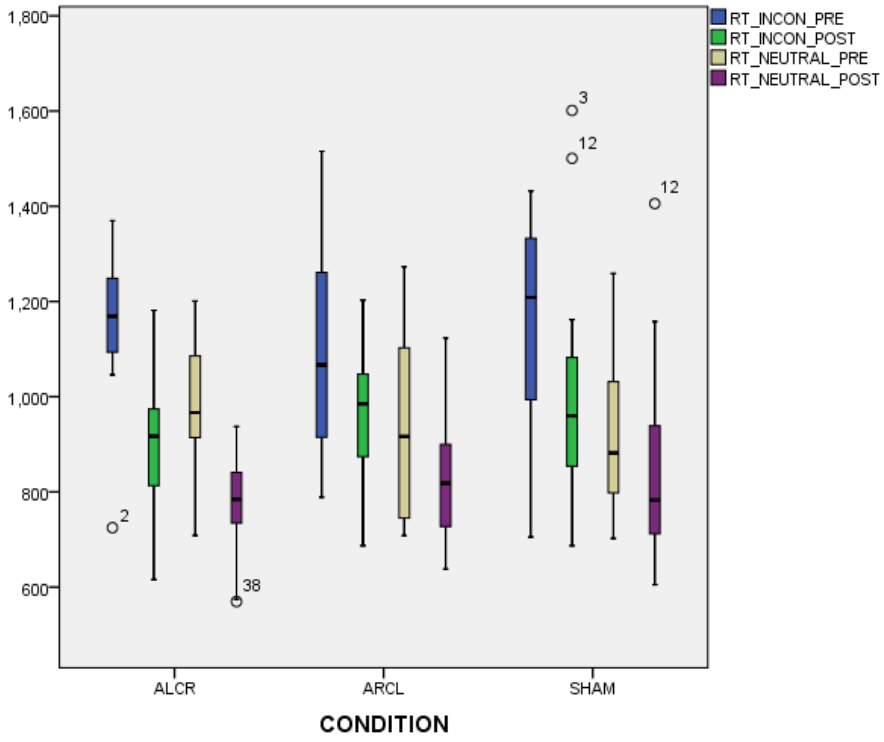
Descriptive Statistics

	CONDITION	Mean	Std. Deviation	N
RT_NEUTRAL_PRE	ALCR	982.87862	124.615104	14
	ARCL	944.29484	202.224414	14
	SHAM	925.51202	164.857219	15
	Total	950.30485	164.648151	43
RT_INCON_PRE	ALCR	1153.69732	153.400675	14
	ARCL	1103.12147	218.540447	14
	SHAM	1146.65246	232.818960	15
	Total	1134.77326	201.589723	43
RT_NEUTRAL_POST	ALCR	772.17841	105.125602	14
	ARCL	838.39997	145.421555	14
	SHAM	858.35365	228.542860	15
	Total	823.80005	169.595528	43
RT_INCON_POST	ALCR	906.78698	160.708455	14
	ARCL	966.44497	156.464214	14
	SHAM	1009.75130	261.642559	15
	Total	962.12830	200.568260	43

Case Processing Summary

		Cases					
		Valid		Missing		Total	
	CONDITION	N	Percent	N	Percent	N	Percent
RT_NEUTRAL_PRE	ALCR	14	100.0%	0	0.0%	14	100.0%
	ARCL	14	100.0%	0	0.0%	14	100.0%
	SHAM	15	100.0%	0	0.0%	15	100.0%
RT_INCON_PRE	ALCR	14	100.0%	0	0.0%	14	100.0%
	ARCL	14	100.0%	0	0.0%	14	100.0%
	SHAM	15	100.0%	0	0.0%	15	100.0%
RT_NEUTRAL_POST	ALCR	14	100.0%	0	0.0%	14	100.0%
	ARCL	14	100.0%	0	0.0%	14	100.0%
	SHAM	15	100.0%	0	0.0%	15	100.0%
RT_INCON_POST	ALCR	14	100.0%	0	0.0%	14	100.0%
	ARCL	14	100.0%	0	0.0%	14	100.0%
	SHAM	15	100.0%	0	0.0%	15	100.0%

Outliers for 3x2 Mixed ANOVA (reaction time)



Univariate Outliers for 3x2 Mixed ANOVA (reaction time)

Extreme Values

	CONDITION			Case Number	Value
Zscore: RT_NEUTRAL_PRE	ALCR	Highest	1	5	1.52245
			2	31	1.04484
			3	14	.95389
			4	8	.82005
			5	10	.43380
		Lowest	1	2	-1.46919
			2	38	-.46020
			3	23	-.43028
			4	21	-.21912
			5	40	-.08848
	ARCL	Highest	1	1	1.95812
			2	6	1.68353
			3	7	1.49364
			4	35	.92543
			5	4	.88183
		Lowest	1	11	-1.47204
			2	26	-1.45281
			3	32	-1.25129
			4	19	-1.24697
			5	42	-.95725
	SHAM	Highest	1	13	1.87188
			2	12	1.24589
			3	17	.86495
			4	24	.51078
			5	3	.47416
		Lowest	1	27	-1.50736
			2	39	-1.35394
			3	34	-1.10940
			4	18	-1.08185
			5	33	-.76709
Zscore: RT_INCON_PRE	ALCR	Highest	1	8	1.16395
			2	14	.80045
			3	20	.73403
			4	5	.56454
			5	31	.41095
		Lowest	1	2	-2.03408
			2	21	-.44034
			3	23	-.31458
			4	40	-.20412
			5	38	-.10427
	ARCL	Highest	1	35	1.88889
			2	7	1.51708
			3	6	.78105
			4	1	.62637
			5	28	.33843
		Lowest	1	11	-1.71578
			2	29	-1.30390
			3	22	-1.12956
			4	32	-1.08999
			5	19	-.87774
	SHAM	Highest	1	12	1.47489
			2	3	1.29915
			3	24	1.28663
			4	15	1.06569
			5	13	.89358
		Lowest	1	27	-2.13159
			2	18	-1.76352
			3	34	-1.22963
			4	39	-.92831
			5	9	-.47116
Zscore: RT_NEUTRAL_POST	ALCR	Highest	1	8	.66894
			2	43	.31414
			3	21	.15154
			4	30	.10034
			5	16	.09787
		Lowest	1	38	-1.49912
			2	2	-1.47071
			3	40	-.81486
			4	10	-.52844
			5	23	-.34716
	ARCL	Highest	1	35	1.76594
			2	1	1.68035
			3	25	.55305
			4	29	.44710
			5	7	.44544
		Lowest	1	11	-1.09439
			2	32	-.77921
			3	22	-.63006
			4	42	-.57117
			5	26	-.54854
	SHAM	Highest	1	12	3.43066
			2	3	1.97022
			3	13	1.96317
			4	17	1.18361
			5	33	.17229
		Lowest	1	27	-1.29097
			2	34	-1.17718
			3	37	-.85052
			4	39	-.69757
			5	41	-.62297
Zscore: RT_INCON_POST	ALCR	Highest	1	30	1.09338
			2	8	.78079
			3	20	.73414
			4	23	.05988
			5	21	-.06387
		Lowest	1	38	-1.72637
			2	2	-1.41974
			3	14	-.74615
			4	40	-.74427
			5	5	-.66860
	ARCL	Highest	1	35	1.19763
			2	7	1.09715
			3	1	1.01769
			4	25	.42530
			5	28	.25383
		Lowest	1	11	-1.37271
			2	22	-1.07932
			3	32	-.79187
			4	42	-.44072
			5	6	-.23394
	SHAM	Highest	1	3	3.18632
			2	12	2.68448
			3	13	.99624
			4	33	.62146
			5	17	.57765
		Lowest	1	27	-1.37275
			2	34	-1.18999
			3	18	-1.00276
			4	37	-.58855
			5	9	-.49079

Shapiro-Wilk for 3x2 Mixed ANOVA (reaction time)

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	CONDITION	Statistic	df	Sig.	Statistic	df	Sig.
RT_NEUTRAL_PRE	ALCR	.121	14	.200*	.974	14	.920
	ARCL	.158	14	.200*	.904	14	.130
	SHAM	.137	15	.200*	.955	15	.613
RT_INCON_PRE	ALCR	.170	14	.200*	.872	14	.044
	ARCL	.120	14	.200*	.958	14	.686
	SHAM	.146	15	.200*	.929	15	.265
RT_NEUTRAL_POST	ALCR	.187	14	.200*	.923	14	.247
	ARCL	.150	14	.200*	.918	14	.203
	SHAM	.243	15	.018	.870	15	.033
RT_INCON_POST	ALCR	.136	14	.200*	.964	14	.784
	ARCL	.113	14	.200*	.960	14	.730
	SHAM	.184	15	.182	.893	15	.075

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Homogeneity of variance for 3x2 Mixed ANOVA (reaction time)

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
RT_NEUTRAL_PRE	2.855	2	40	.069
RT_INCON_PRE	2.550	2	40	.091
RT_NEUTRAL_POST	3.370	2	40	.044
RT_INCON_POST	1.714	2	40	.193

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + CONDITION
Within Subjects Design: TIME_NEUTRAL + TIME_INCON + TIME_NEUTRAL * TIME_INCON

Homogeneity of covariance for 3x2 Mixed ANOVA (Reaction Time)

Box's Test of Equality of Covariance Matrices[a]

Box's M	31.528
F	1.345
df1	20
df2	5690.465
Sig.	.139

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

a. Design: Intercept + CONDITION
Within Subjects Design: TIME_NEUTRAL + TIME_INCON + TIME_NEUTRAL * TIME_INCON

Sphericity for 3x2 Mixed ANOVA (reaction time)

Mauchly's Test of Sphericity[a]

Measure: REACTION_TIME

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
TIME_NEUTRAL	1.000	.000	0	.	1.000	1.000	1.000
TIME_INCON	1.000	.000	0	.	1.000	1.000	1.000
TIME_NEUTRAL * TIME_INCON	1.000	.000	0	.	1.000	1.000	1.000

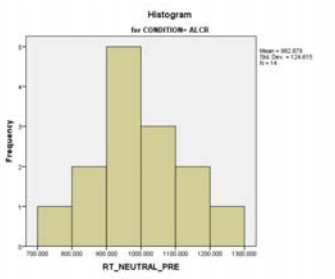
Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

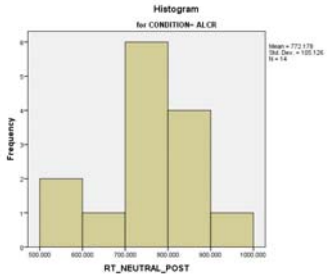
a. Design: Intercept + CONDITION
Within Subjects Design: TIME_NEUTRAL + TIME_INCON + TIME_NEUTRAL * TIME_INCON

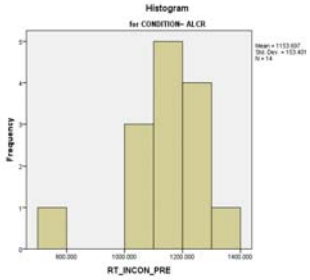
b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

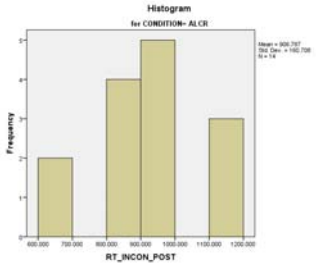
Histograms for 3x2 Mixed ANOVA (reaction time)

Condition: ALCR

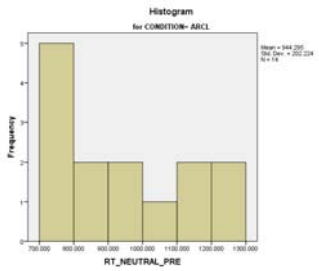


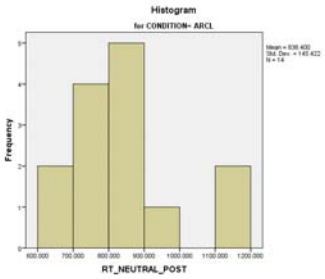


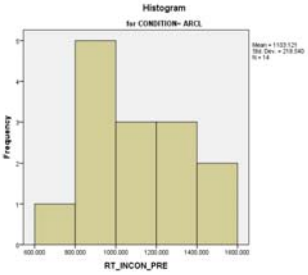


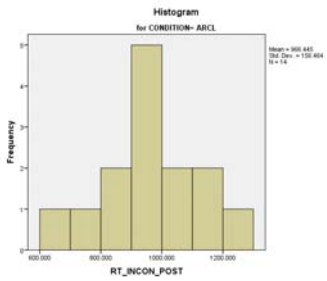


Condition: ARCL

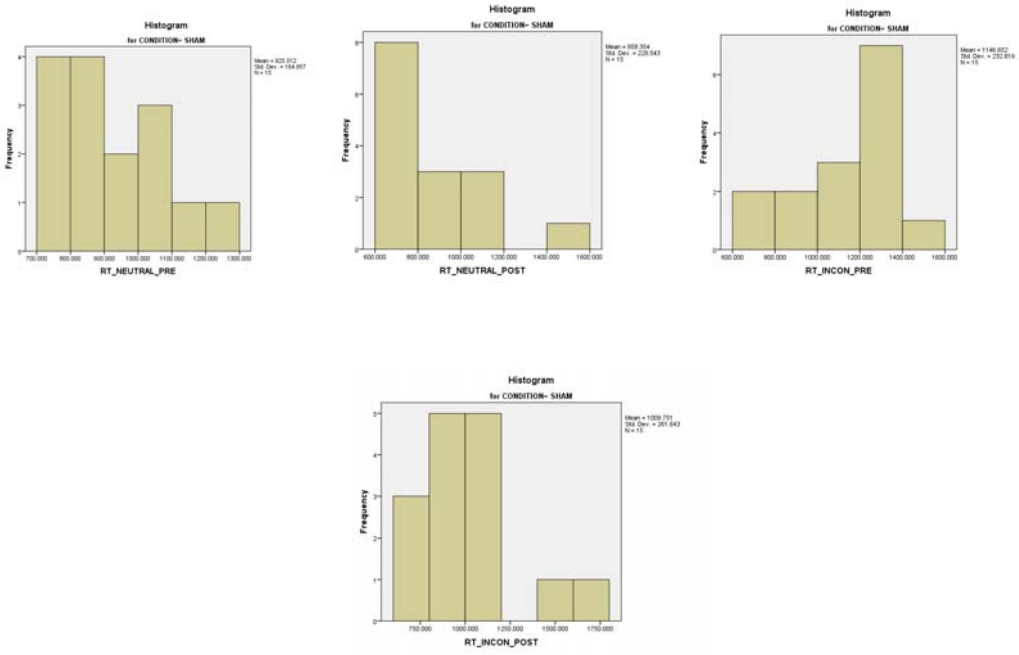






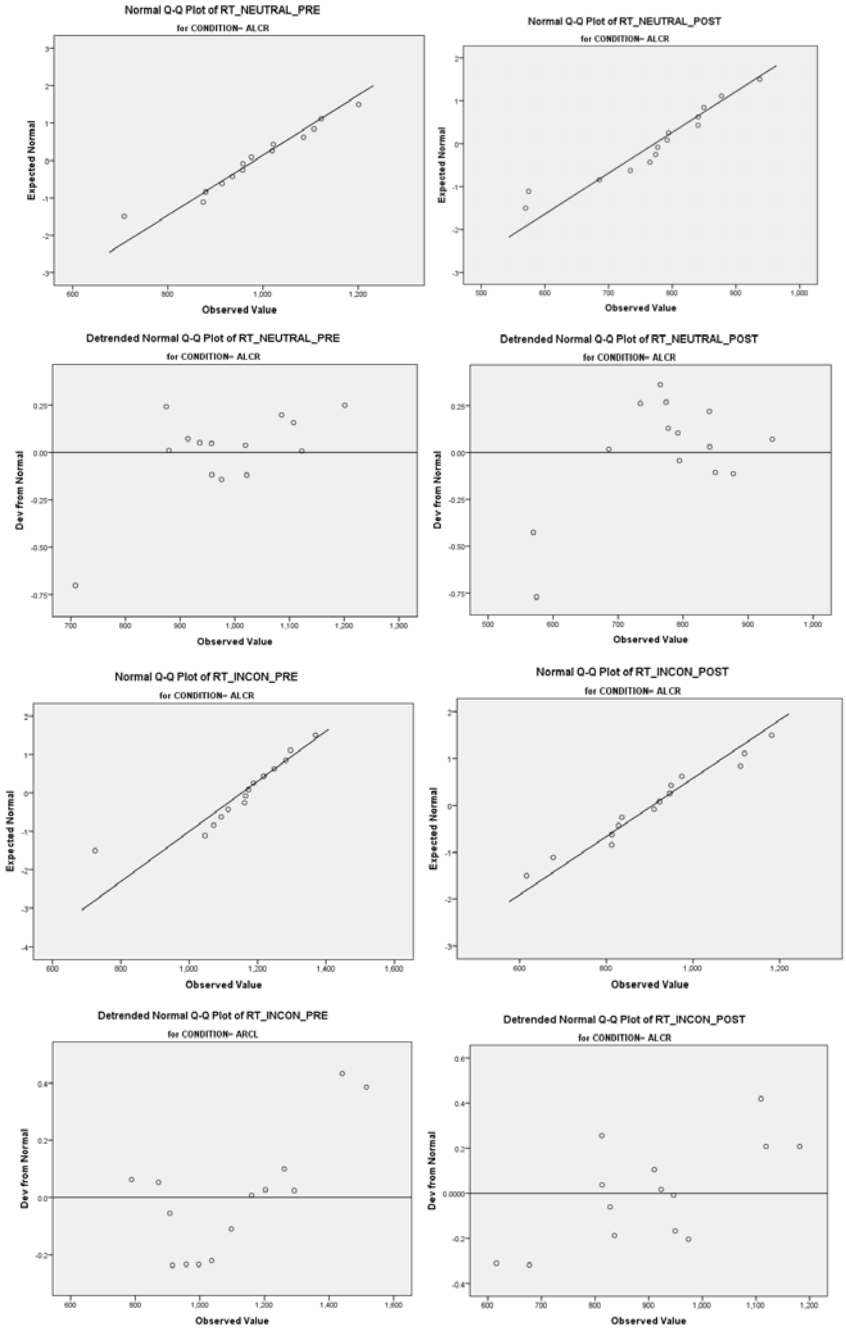


Condition: SHAM

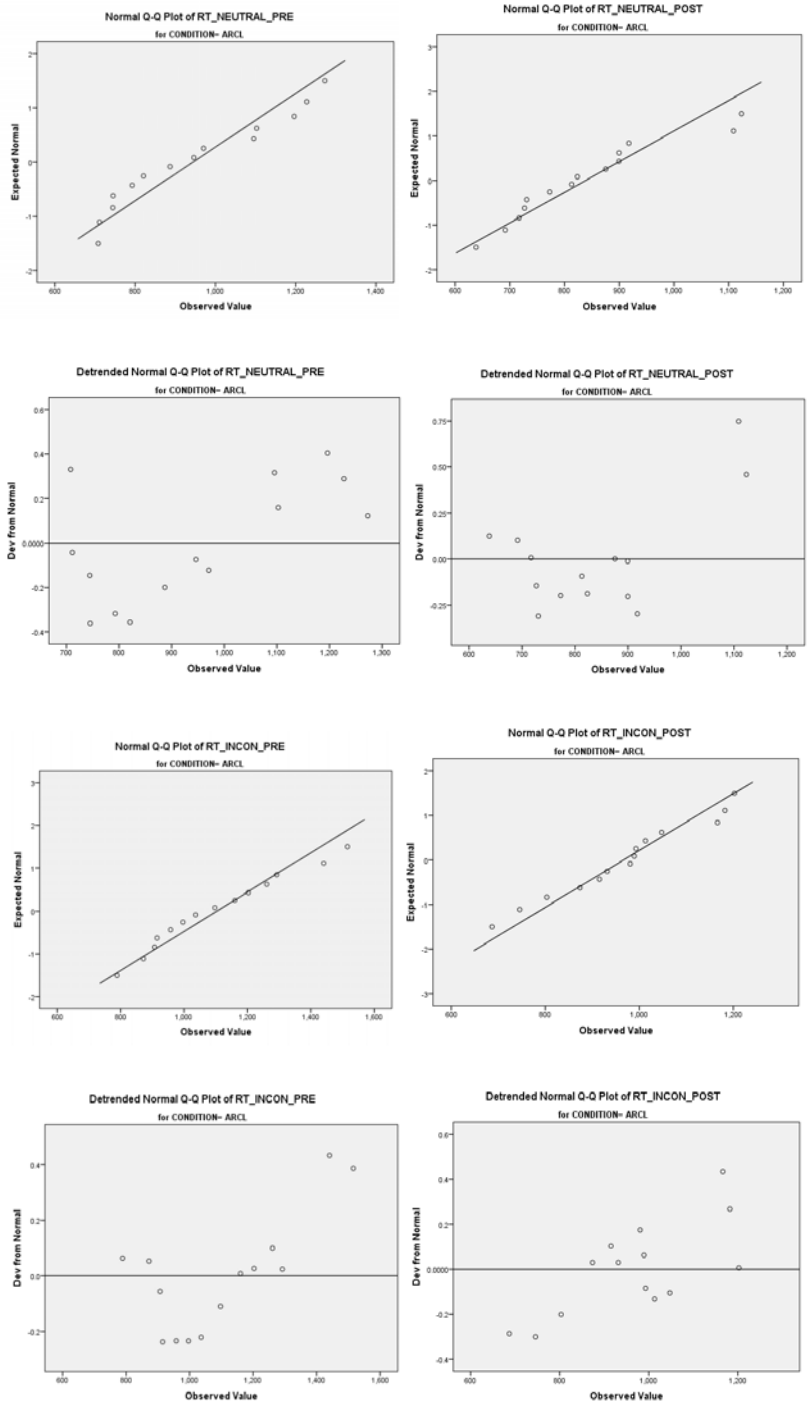


Normal and Detrended Q-Q Plots for 3x2 Mixed ANOVA (reaction time)

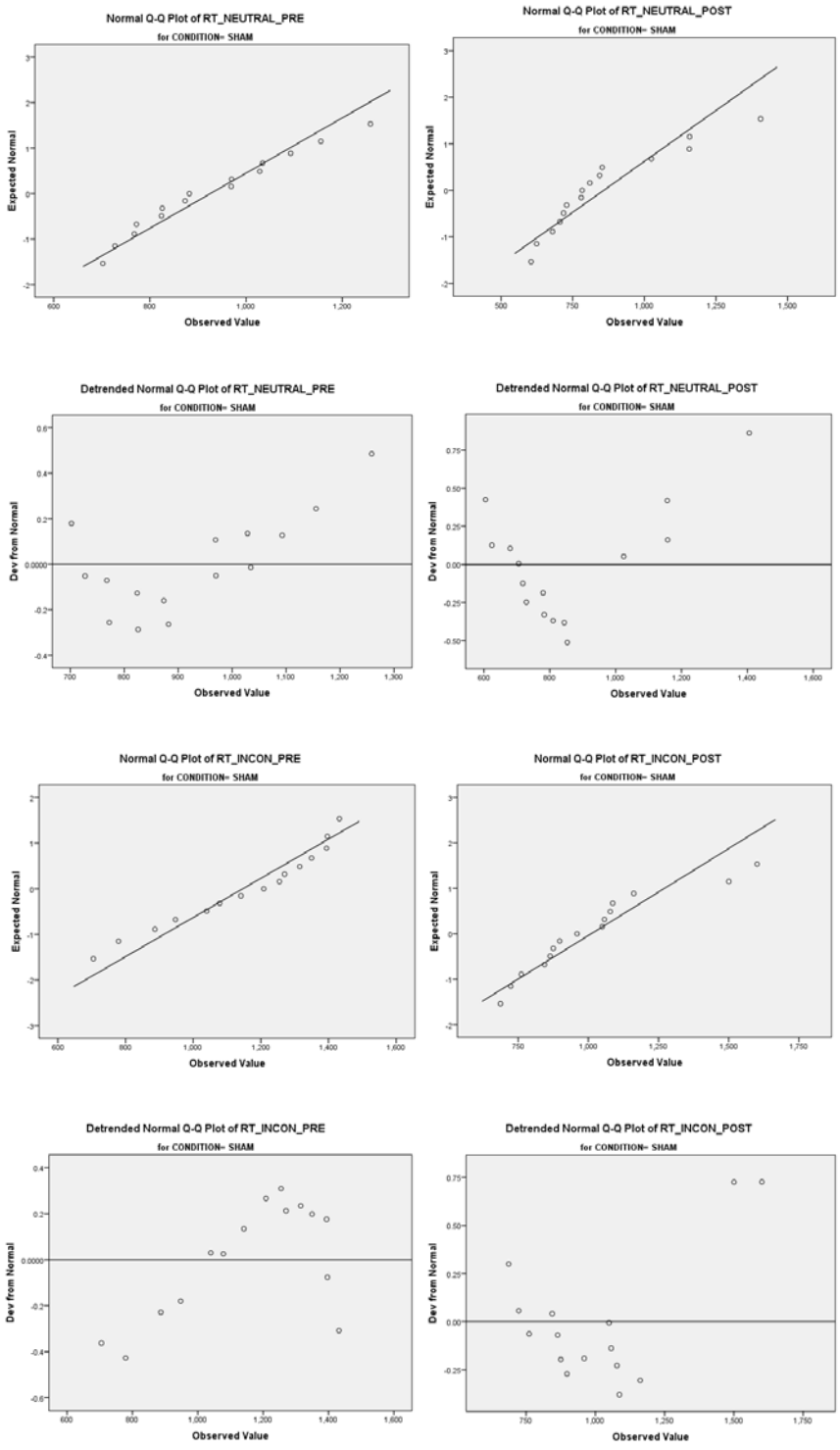
Condition: ALCR



Condition: ARCL



Condition: SHAM



Supplementary Material J: Assumptions Testing for Error

A 3 X 2 factorial mixed ANOVA was conducted in order to test whether there were any differences between pre and post error and the experimental conditions (Anodal, Cathodal, and Sham). Before running the ANOVA the data was scanned for outliers and the assumptions of scale of measurement, independence, normality, homogeneity of variance, homogeneity of covariance and sphericity were tested (Allen & Bennett, 2012).

Assumption Testing

Outliers. Outliers were defined at a score that is 3.29 standard deviations above or below the mean (Tabacknick & Fidell, 2007). Upon inspection of the statistics, only one case was deemed as an outlier. This case was retained as this experiment requires the pure measure of error rates pre and post tDCS.

Scale of measurement. The dependant variable (error) provided ratio data; therefore the assumption of scale of measure was met.

Normality. Normality was assessed by inspecting the Shapiro-Wilk statistics, skewness and kurtosis, and the relevant histograms. For all of the Independent variables the Shapiro-Wilk statistic was significant indicating that the data were not normally distributed. The majority of the skewness and kurtosis statistics were within ± 1.96 except in post-test incongruent error across all conditions and pre-test neutral error rates in the SHAM condition. Refer to Table 2 for the normality statistics. Inspection of the histograms indicates that the data were positively skewed; therefore Square Root Transformation was performed. See Table 2 for skewness and kurtosis statistics.
See Supplementary Material L for Homogeneity of Variance, Homogeneity of Covariance and Sphericity statistics for Transformed Error.

Table 2.

Shapiro-Wilk p-value, and Skewness and Kurtosis Statistics for Error According to Trial Type and Experimental Conditions.

Condition	Dependent Variable	Shapiro-Wilk *p* value	Skewness Statistic	Kurtosis Statistic
ALCR	Post-test incongruent error	< .000	1.532	2.986*
ARCL	Post-test incongruent error	< .000	1.888	4.431*
SHAM	pre-test neutral error	< .001	2.045*	4.568*
	Post-test incongruent error	< .000	1.441	2.817*

Note. * denotes violations of normality

Supplementary Material K: SPSS Output for Error

Descriptive statistics for 3x2 Mixed ANOVA (error)

Within-Subjects Factors

Measure: REACTION_TIME

TIME_NEUTRAL	TIME_INCON	Dependent Variable
1	1	RT_NEUTRAL_PRE
	2	RT_INCON_PRE
2	1	RT_NEUTRAL_POST
	2	RT_INCON_POST

Between-Subjects Factors

		Value Label	N
CONDITION	1	ALCR	14
	2	ARCL	14
	3	SHAM	15

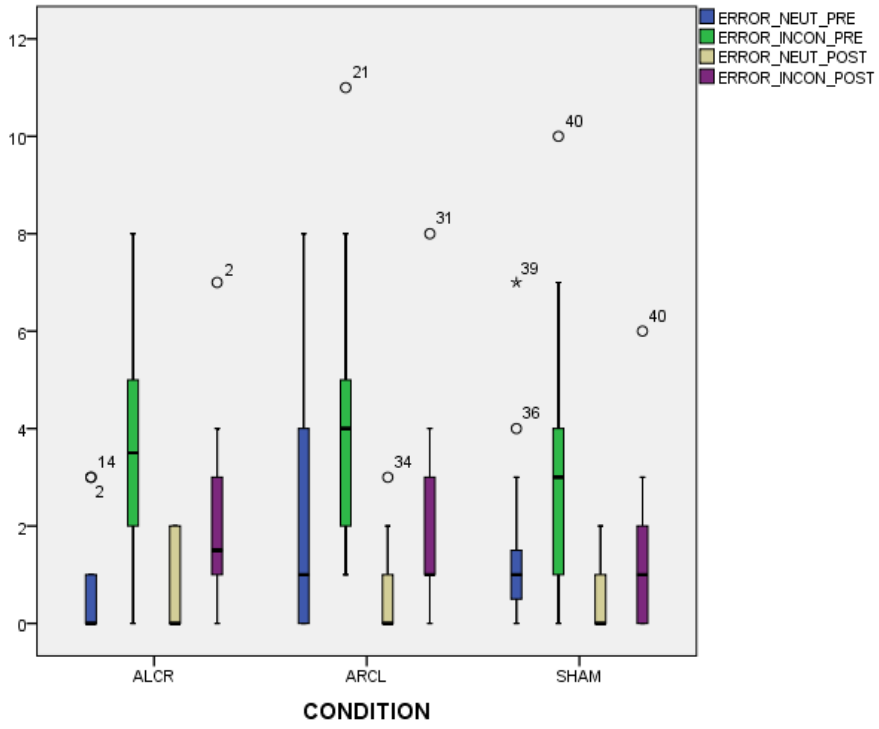
Descriptive Statistics

	CONDITION	Mean	Std. Deviation	N
RT_NEUTRAL_PRE	ALCR	982.87862	124.615104	14
	ARCL	944.29484	202.224414	14
	SHAM	925.51202	164.857219	15
	Total	950.30485	164.648151	43
RT_INCON_PRE	ALCR	1153.69732	153.400675	14
	ARCL	1103.12147	218.540447	14
	SHAM	1146.65246	232.818960	15
	Total	1134.77326	201.589723	43
RT_NEUTRAL_POST	ALCR	772.17841	105.125602	14
	ARCL	838.39997	145.421555	14
	SHAM	858.35365	228.542860	15
	Total	823.80005	169.595528	43
RT_INCON_POST	ALCR	906.78698	160.708455	14
	ARCL	966.44497	156.464214	14
	SHAM	1009.75130	261.642559	15
	Total	962.12830	200.568260	43

Case Processing Summary

		Cases					
		Valid		Missing		Total	
	CONDITION	N	Percent	N	Percent	N	Percent
RT_NEUTRAL_PRE	ALCR	14	100.0%	0	0.0%	14	100.0%
	ARCL	14	100.0%	0	0.0%	14	100.0%
	SHAM	15	100.0%	0	0.0%	15	100.0%
RT_INCON_PRE	ALCR	14	100.0%	0	0.0%	14	100.0%
	ARCL	14	100.0%	0	0.0%	14	100.0%
	SHAM	15	100.0%	0	0.0%	15	100.0%
RT_NEUTRAL_POST	ALCR	14	100.0%	0	0.0%	14	100.0%
	ARCL	14	100.0%	0	0.0%	14	100.0%
	SHAM	15	100.0%	0	0.0%	15	100.0%
RT_INCON_POST	ALCR	14	100.0%	0	0.0%	14	100.0%
	ARCL	14	100.0%	0	0.0%	14	100.0%
	SHAM	15	100.0%	0	0.0%	15	100.0%

Outliers for 3x2 Mixed ANOVA (error)



Univariate Outliers for 3x2 Mixed ANOVA (error)

Descriptives

	CONDITION			Statistic	Std. Error
Zscore (ERROR_NEUT_PRE)	ALCR	Mean		-.3920199	.14610929
		95% Confidence Interval for Mean	Lower Bound	-.7076659	
			Upper Bound	-.0763700	
		5% Trimmed Mean		-.4401480	
		Median		-.7168844	
		Variance		.299	
		Std. Deviation		.54669091	
		Minimum		-.71688	
		Maximum		.79915	
		Range		1.51603	
		Interquartile Range		.50534	
		Skewness		1.697	.597
		Kurtosis		1.817	1.154
	ARCL	Mean		.3299011	.34520650
		95% Confidence Interval for Mean	Lower Bound	-.4158722	
			Upper Bound	1.0756744	
		5% Trimmed Mean		.2216130	
		Median		-.2115397	
		Variance		1.668	
		Std. Deviation		1.29164444	
		Minimum		-.71688	
		Maximum		3.32587	
		Range		4.04276	
		Interquartile Range		2.14772	
		Skewness		1.133	.597
		Kurtosis		.489	1.154
	SHAM	Mean		.0579775	.24592455
		95% Confidence Interval for Mean	Lower Bound	-.4694782	
			Upper Bound	.5854332	
		5% Trimmed Mean		-.0524496	
		Median		-.2115397	
		Variance		.907	
		Std. Deviation		.95246168	
		Minimum		-.71688	
		Maximum		2.82053	
		Range		3.53741	
		Interquartile Range		1.01069	
		Skewness		2.045	.580
		Kurtosis		4.568	1.121
Zscore (ERROR_INCON_PRE)	ALCR	Mean		-.0214181	.23757401
		95% Confidence Interval for Mean	Lower Bound	-.5346655	
			Upper Bound	.4918293	
		5% Trimmed Mean		-.0394765	
		Median		-.0485057	
		Variance		.790	
		Std. Deviation		.88892054	
		Minimum		-1.37580	
		Maximum		1.65801	
		Range		3.03381	
		Interquartile Range		1.32729	
		Skewness		.230	.597
		Kurtosis		-.860	1.154
	ARCL	Mean		.1952827	.29174243
		95% Confidence Interval for Mean	Lower Bound	-.4349885	
			Upper Bound	.8255539	
		5% Trimmed Mean		.1170296	
		Median		.1411075	
		Variance		1.192	
		Std. Deviation		1.09160021	
		Minimum		-.99657	
		Maximum		2.79569	
		Range		3.79226	
		Interquartile Range		1.42210	
		Skewness		1.121	.597
		Kurtosis		1.180	1.154
	SHAM	Mean		-.1622736	.26993537
		95% Confidence Interval for Mean	Lower Bound	-.7412274	
			Upper Bound	.4166801	
		5% Trimmed Mean		-.2381189	
		Median		-.2381189	
		Variance		1.093	
		Std. Deviation		1.04545521	
		Minimum		-1.37580	
		Maximum		2.41647	
		Range		3.79226	
		Interquartile Range		1.13768	
		Skewness		1.200	.580
		Kurtosis		1.241	1.121
Zscore (ERROR_NEUT_POST)	ALCR	Mean		.0992441	.29079105
		95% Confidence Interval for Mean	Lower Bound	-.5289718	
			Upper Bound	.7274600	
		5% Trimmed Mean		.0527572	
		Median		-.6538434	
		Variance		1.184	
		Std. Deviation		1.08804050	
		Minimum		-.65384	
		Maximum		1.68910	
		Range		2.34294	
		Interquartile Range		2.34294	
		Skewness		.857	.597
		Kurtosis		-1.354	1.154
	ARCL	Mean		.0992441	.31565820
		95% Confidence Interval for Mean	Lower Bound	-.5826940	
			Upper Bound	.7811822	
		5% Trimmed Mean		-.0123244	
		Median		-.6538434	
		Variance		1.395	
		Std. Deviation		1.18108485	
		Minimum		-.65384	
		Maximum		2.86056	
		Range		3.51441	
		Interquartile Range		1.46434	
		Skewness		1.383	.597
		Kurtosis		.805	1.154
	SHAM	Mean		-.1852556	.19130014
		95% Confidence Interval for Mean	Lower Bound	-.5955536	
			Upper Bound	.2250424	
		5% Trimmed Mean		-.2633536	
		Median		-.6538434	
		Variance		.549	
		Std. Deviation		.74090227	
		Minimum		-.65384	
		Maximum		1.68910	
		Range		2.34294	
		Interquartile Range		1.17147	
		Skewness		1.407	.580
		Kurtosis		1.264	1.121
Zscore (ERROR_INCON_POST)	ALCR	Mean		.0493651	.27437017
		95% Confidence Interval for Mean	Lower Bound	-.5433756	
			Upper Bound	.6421058	
		5% Trimmed Mean		-.0449771	
		Median		-.1822021	
		Variance		1.054	
		Std. Deviation		1.02655915	
		Minimum		-.99269	
		Maximum		2.78958	
		Range		3.78227	
		Interquartile Range		1.21573	
		Skewness		1.532	.597
		Kurtosis		2.986	1.154
	ARCL	Mean		.1266542	.30219228
		95% Confidence Interval for Mean	Lower Bound	-.5262925	
			Upper Bound	.7794009	
		5% Trimmed Mean		.0107705	
		Median		-.4523639	
		Variance		1.278	
		Std. Deviation		1.13059997	
		Minimum		-.99269	
		Maximum		3.32990	
		Range		4.32259	
		Interquartile Range		1.08855	
		Skewness		1.888	.597
		Kurtosis		4.431	1.154
	SHAM	Mean		-.1641913	.22903764
		95% Confidence Interval for Mean	Lower Bound	-.6554282	
			Upper Bound	.3270455	
		5% Trimmed Mean		-.2522441	
		Median		-.4523639	
		Variance		.787	
		Std. Deviation		.88705895	
		Minimum		-.99269	
		Maximum		2.24925	
		Range		3.24194	
		Interquartile Range		1.08065	
		Skewness		1.441	.580
		Kurtosis		2.817	1.121

Shapiro-Wilk for 3x2 Mixed ANOVA (error)

Tests of Normality

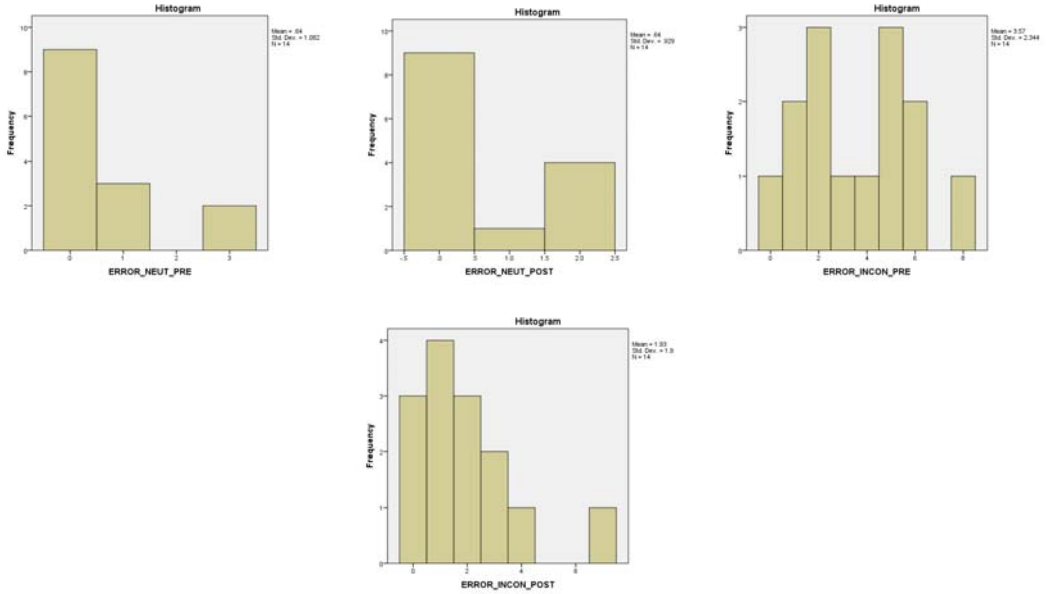
		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	CONDITION	Statistic	df	Sig.	Statistic	df	Sig.
ERROR_NEUT_PRE	ALCR	.367	14	.000	.640	14	.000
	ARCL	.234	14	.037	.817	14	.008
	SHAM	.345	15	.000	.736	15	.001
ERROR_INCON_PRE	ALCR	.177	14	.200*	.952	14	.584
	ARCL	.234	14	.036	.889	14	.078
	SHAM	.188	15	.163	.877	15	.042
ERROR_NEUT_POST	ALCR	.398	14	.000	.645	14	.000
	ARCL	.381	14	.000	.697	14	.000
	SHAM	.403	15	.000	.667	15	.000
ERROR_INCON_POST	ALCR	.199	14	.137	.852	14	.023
	ARCL	.267	14	.008	.789	14	.004
	SHAM	.188	15	.161	.833	15	.010

*. This is a lower bound of the true significance.

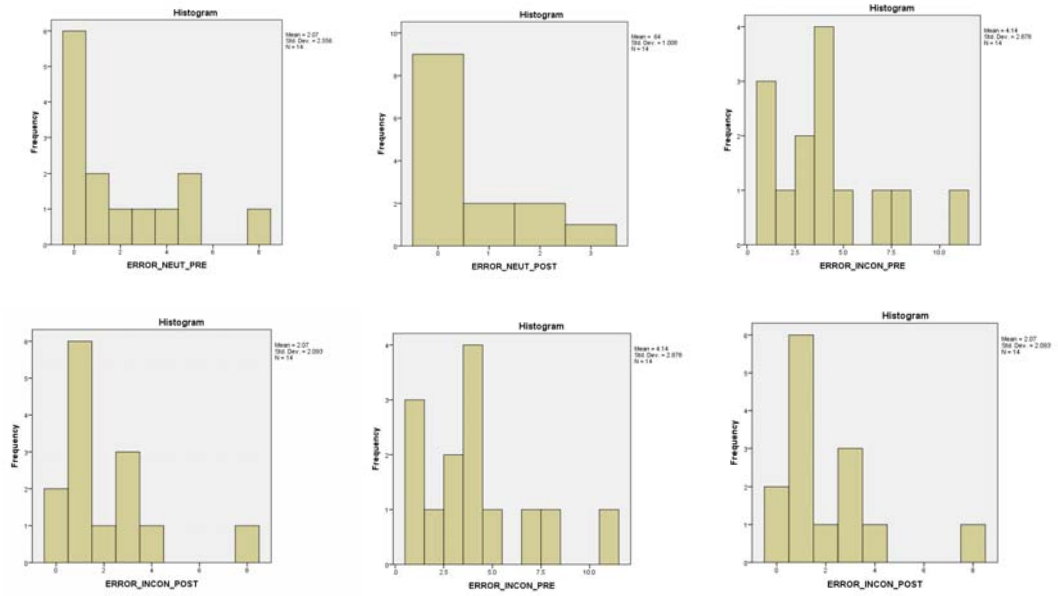
a. Lilliefors Significance Correction

Histograms for 3x2 Mixed ANOVA (error)

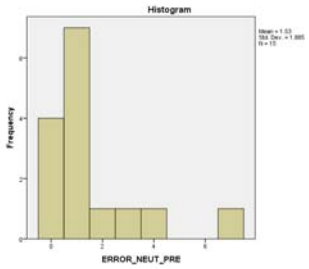
Condition: ALCR

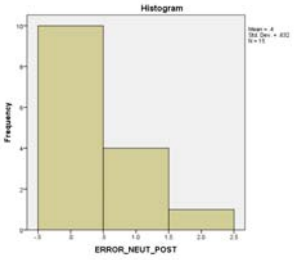


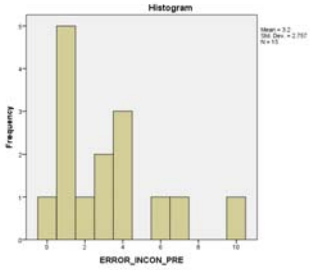
Condition: ARCL

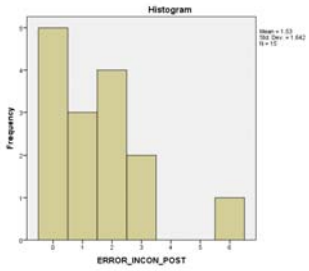


Condition: SHAM



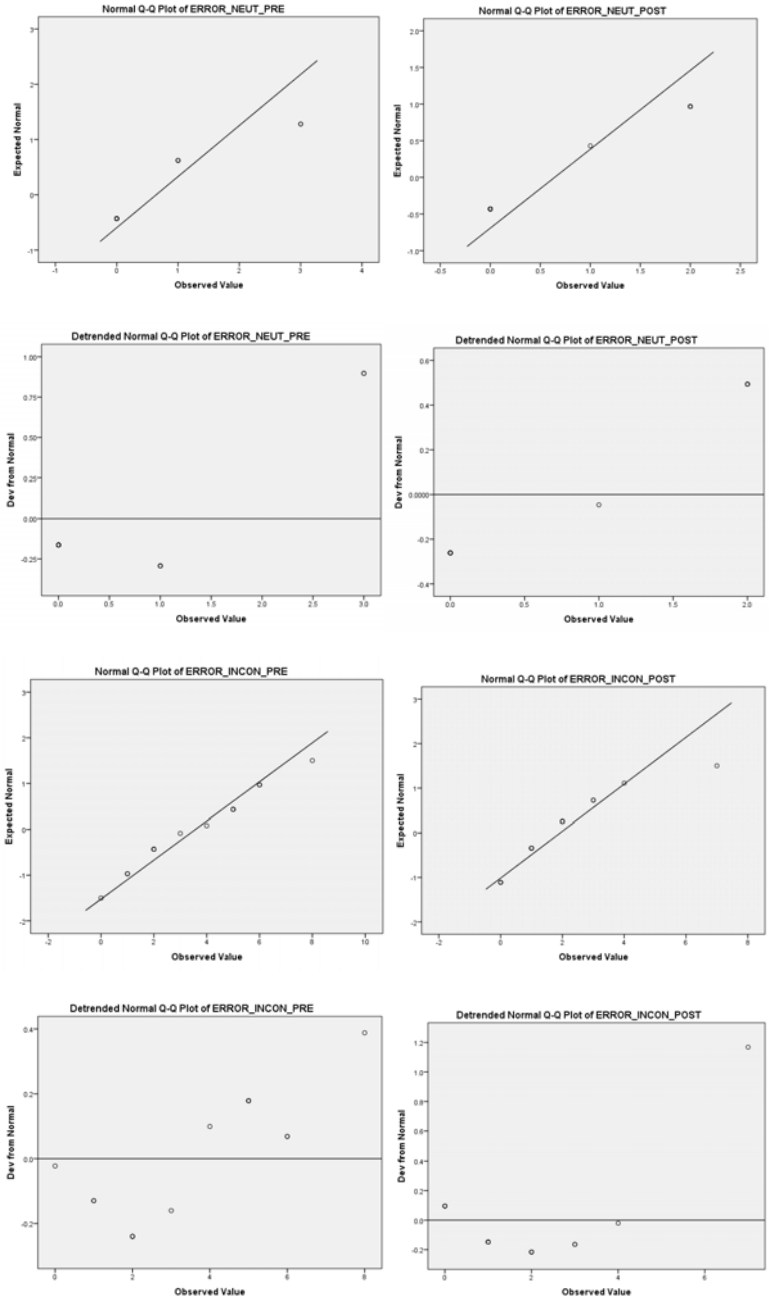




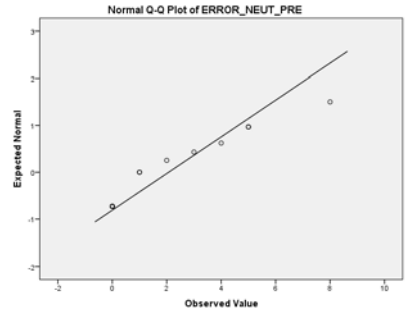


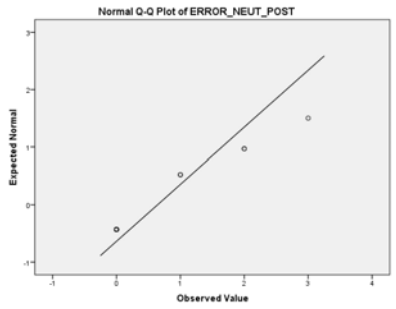
Normal and Detrended Q-Q Plots for 3x2 Mixed ANOVA (error)

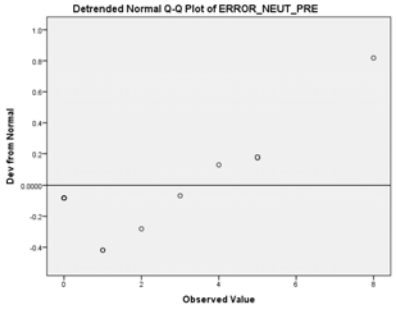
Condition: ALCR

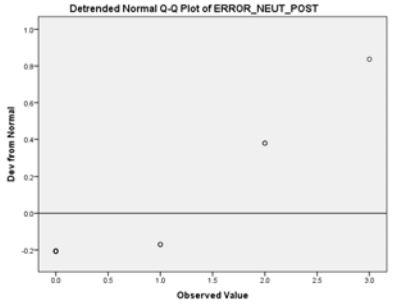


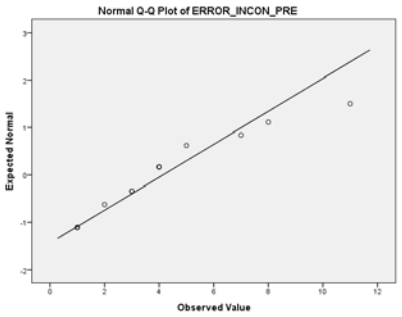
Condition: ARCL

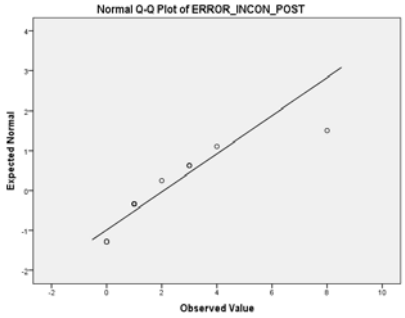


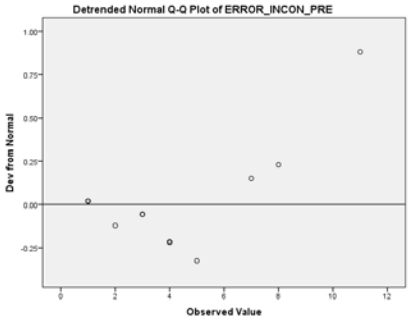


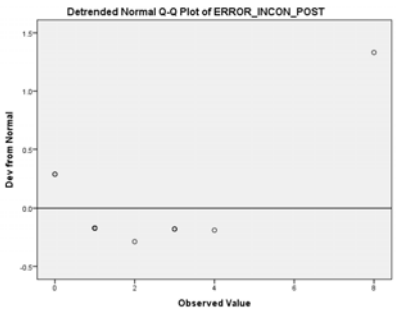




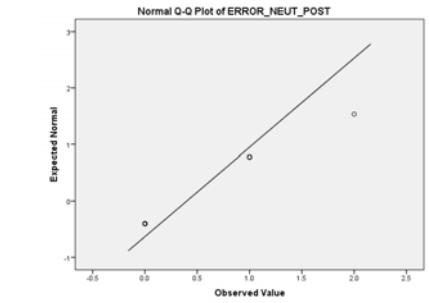


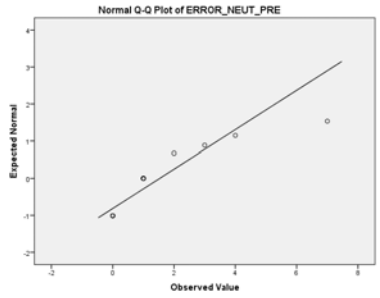


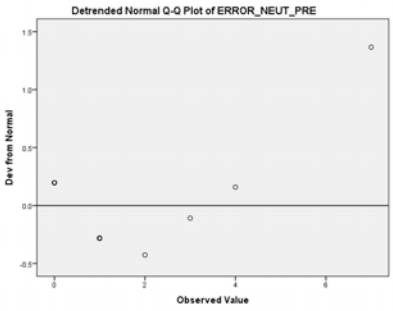


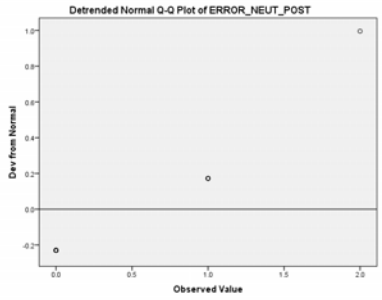


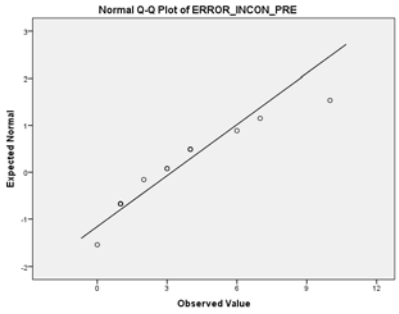
Condition: SHAM

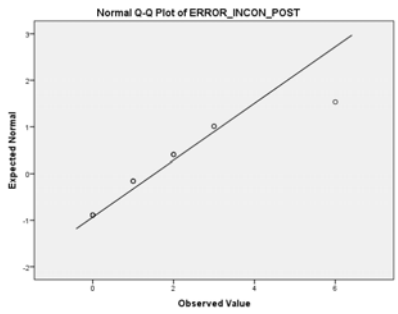


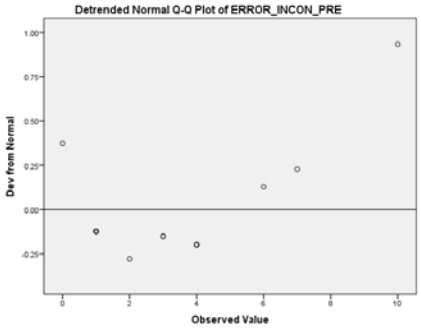


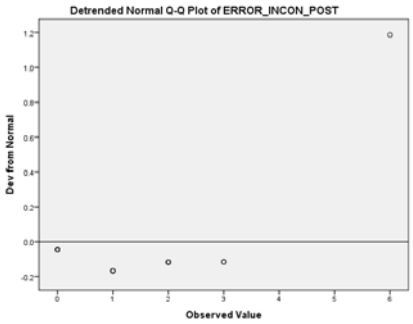












Supplementary Material L: Assumptions Testing for Transformed Error

Normality. Normality was assessed by inspecting the Shapiro-Wilk statistics, skewness and kurtosis, and the relevant histograms. For all of the Independent variables the Shapiro-Wilk statistic was significant indicating that the data were not normally distributed. All of the skewness and kurtosis statistics were within ± 1.96. Transforming the error rates improved most of the distribution and the ANOVA was analysed with the square root error rates.

Homogeneity of Variance. The Levene's test for equality of variances for pre-test neutral error rates was non-significant (F= 2.65, p=.083) indicating that homogeneity variance was not violated. The homogeneity of variance assumption was also not violated for pre-test incongruent error rates (F= .301, p=.74), post-test neutral error rates (F= 1.53, p=.23), or post-test incongruent error rates (F= .119, p=.89).

Homogeneity of Covariance. Box's M statistic for indicated that the homogeneity of intercorrelations assumption was not violated, p = .753.

Sphericity. Sphericity is assumed as the repeated measures factor (pre/post) has only two levels.

Supplementary Material M: SPSS Output for Transformed Error

Homogeneity of variance for 3x2 Mixed ANOVA (square root error)

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
SQRT_ERROR_NEUT_PRE	2.647	2	40	.083
SQRT_ERROR_INCON_PRE	.301	2	40	.742
SQRT_ERROR_NEUT_POST	1.534	2	40	.228
SQRT_ERROR_INCON_POST	.119	2	40	.888

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + CONDITION
Within Subjects Design: TIME + TRIAL_TYPE + TIME * TRIAL_TYPE

Homogeneity of covariance for 3x2 Mixed ANOVA (square root error)

Box's Test of Equality of Covariance Matrices[a]

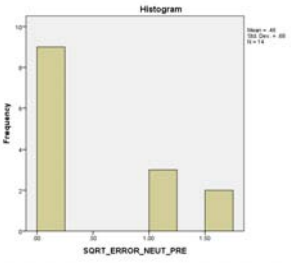
Box's M	18.046
F	.770
df1	20
df2	5690.465
Sig.	.753

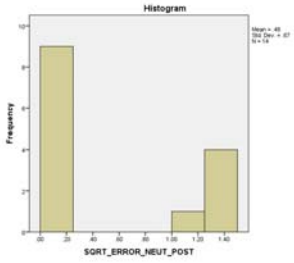
Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

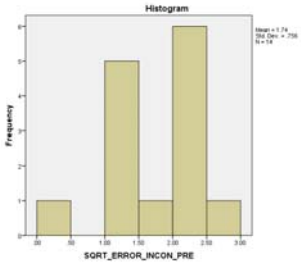
a. Design: Intercept + CONDITION
Within Subjects Design: TIME + TRIAL_TYPE + TIME * TRIAL_TYPE

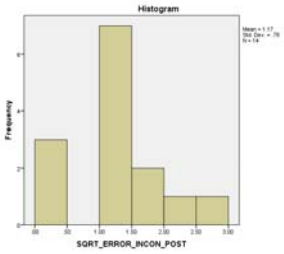
Histograms of Transformed error for 3x2 Mixed ANOVA

Condition: ALCR

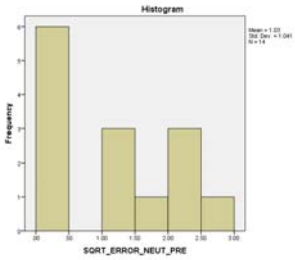


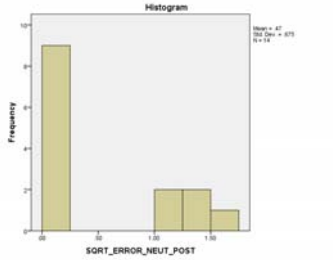


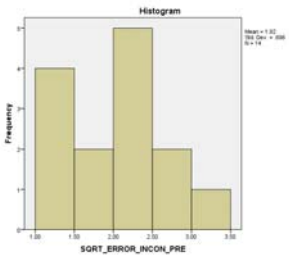


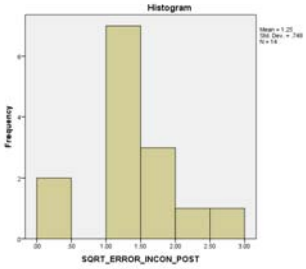


Condition: ARCL

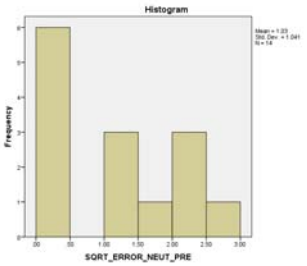


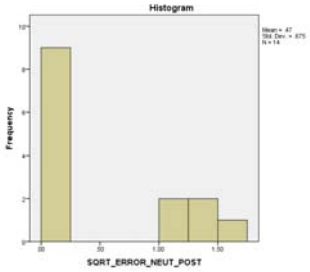


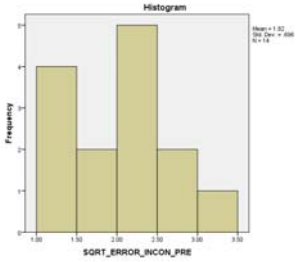


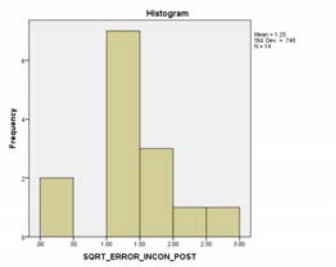


Condition: SHAM



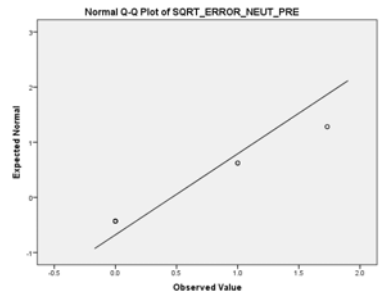


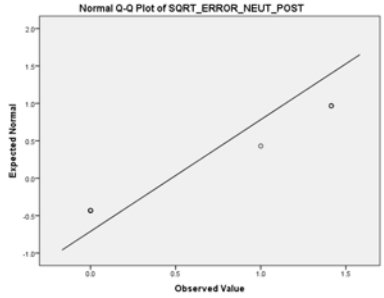


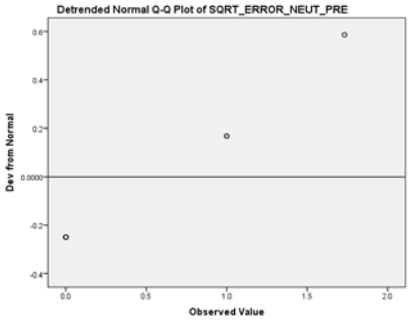


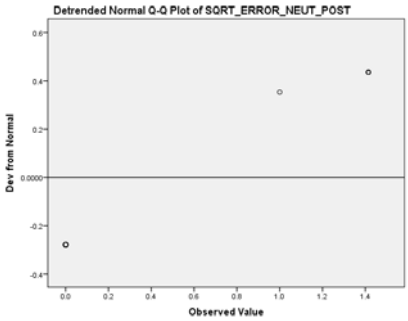
Normal and Detrended Q-Q Plots for 3x2 Mixed ANOVA (Transformed error)

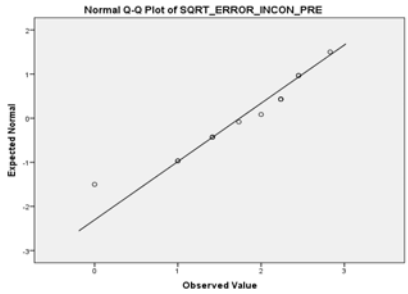
Condition: ALCR

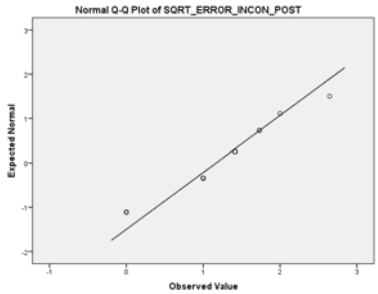


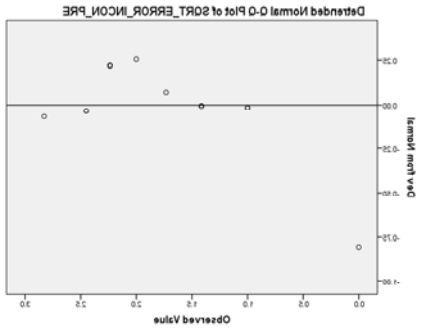


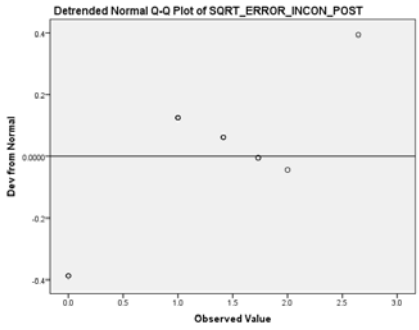




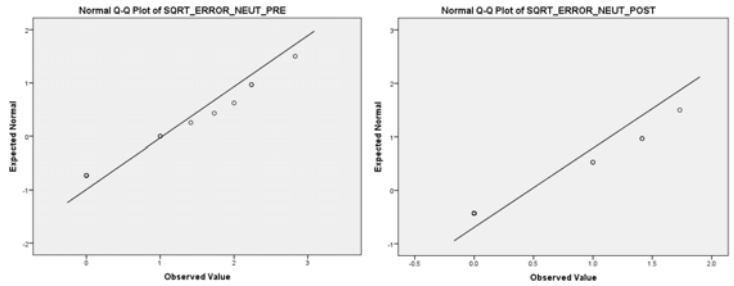


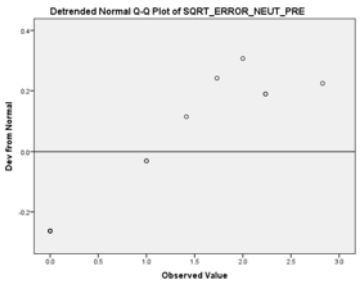


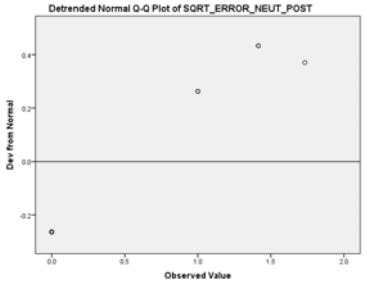


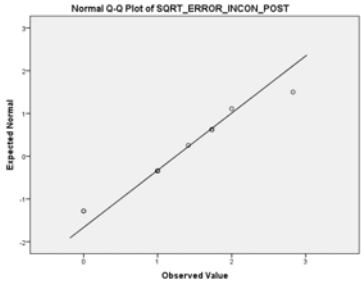


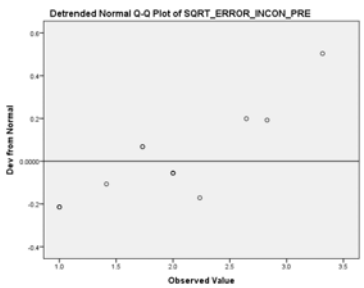
Condition: ARCL

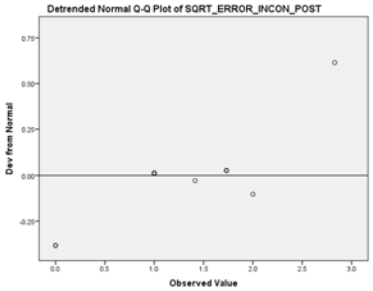




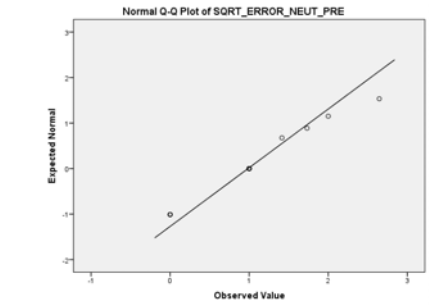


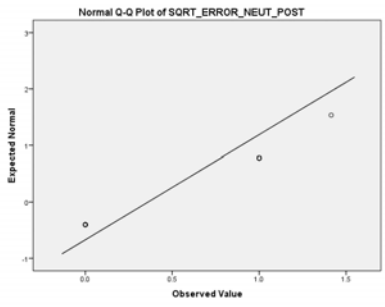


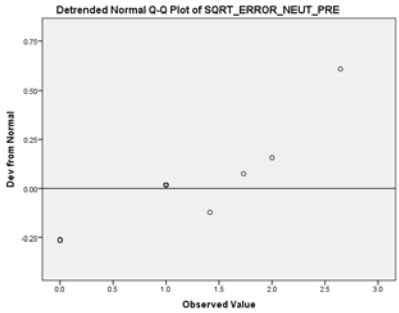


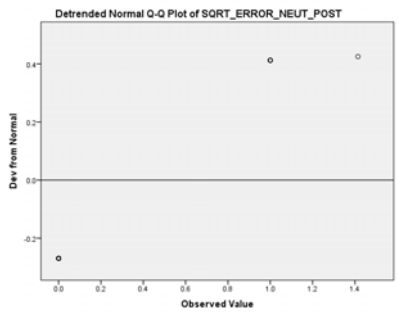


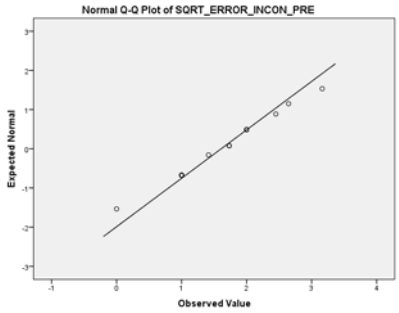
Condition: SHAM

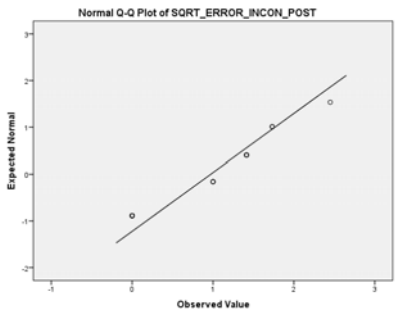


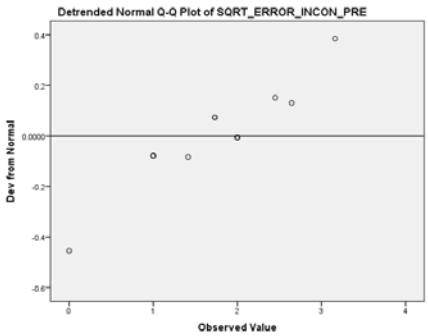


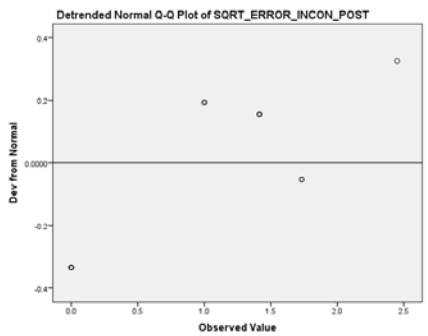












Supplementary Material N: Descriptive Statistics for 3x2 Mixed ANOVA

Statistics

		GENDER	AGE
N	Valid	43	43
	Missing	0	0
Mean		1.65	24.51
Std. Deviation		.482	4.718

GENDER

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	MALE	15	34.9	34.9	34.9
	FEMALE	28	65.1	65.1	100.0
	Total	43	100.0	100.0	

Within-Subjects Factors

Measure	TIME	TRIAL_TYPE	Dependent Variable
REACTION_TIME	1	1	RT_NEUTRAL_PRE
		2	RT_INCON_PRE
	2	1	RT_NEUTRAL_POST
		2	RT_INCON_POST
ERROR	1	1	SQRT_ERROR_NEUT_PRE
		2	SQRT_ERROR_INCON_PRE
	2	1	SQRT_ERROR_NEUT_POST
		2	SQRT_ERROR_INCON_POST

Between-Subjects Factors

		Value Label	N
CONDITION	1	ALCR	14
	2	ARCL	14
	3	SHAM	15

Descriptive Statistics

	CONDITION	Mean	Std. Deviation	N
RT_NEUTRAL_PRE	ALCR	982.87862	124.615104	14
	ARCL	944.29484	202.224414	14
	SHAM	925.51202	164.857219	15
	Total	950.30485	164.648151	43
RT_INCON_PRE	ALCR	1153.69732	153.400675	14
	ARCL	1103.12147	218.540447	14
	SHAM	1146.65246	232.818960	15
	Total	1134.77326	201.589723	43
RT_NEUTRAL_POST	ALCR	772.17841	105.125602	14
	ARCL	838.39997	145.421555	14
	SHAM	858.35365	228.542860	15
	Total	823.80005	169.595528	43
RT_INCON_POST	ALCR	906.78698	160.708455	14
	ARCL	966.44497	156.464214	14
	SHAM	1009.75130	261.642559	15
	Total	962.12830	200.568260	43
SQRT_ERROR_NEUT_PRE	ALCR	.4617	.68024	14
	ARCL	1.0319	1.04116	14
	SHAM	.9861	.77520	15
	Total	.8303	.86404	43
SQRT_ERROR_INCON_PRE	ALCR	1.7436	.75643	14
	ARCL	1.9218	.69579	14
	SHAM	1.6091	.80906	15
	Total	1.7547	.74971	43
SQRT_ERROR_NEUT_POST	ALCR	.4755	.66994	14
	ARCL	.4686	.67515	14
	SHAM	.3609	.53757	15
	Total	.4333	.61581	43
SQRT_ERROR_INCON_POST	ALCR	1.1680	.77953	14
	ARCL	1.2456	.74822	14
	SHAM	.9714	.79493	15
	Total	1.1247	.76544	43

Supplementary Material O: SPSS Output for 3x2 Mixed ANOVA

Homogeneity of variance for 3x2 Mixed ANOVA

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
RT_NEUTRAL_PRE	2.855	2	40	.069
RT_INCON_PRE	2.550	2	40	.091
RT_NEUTRAL_POST	3.370	2	40	.044
RT_INCON_POST	1.714	2	40	.193
SQRT_ERROR_NEUT_PRE	2.647	2	40	.083
SQRT_ERROR_INCON_PRE	.301	2	40	.742
SQRT_ERROR_NEUT_POST	1.534	2	40	.228
SQRT_ERROR_INCON_POST	.119	2	40	.888

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + CONDITION
Within Subjects Design: TIME + TRIAL_TYPE + TIME * TRIAL_TYPE

Homogeneity of covariance for 3x2 Mixed ANOVA

Box's Test of Equality of Covariance Matrices[a]

Box's M	115.436
F	1.128
df1	72
df2	4420.045
Sig.	.216

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

a. Design: Intercept + CONDITION
Within Subjects Design: TIME + TRIAL_TYPE + TIME * TRIAL_TYPE

Sphericity for 3x2 Mixed ANOVA

Mauchly's Test of Sphericity[a]

						Epsilon[b]		
Within Subjects Effect	Measure	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
TIME	REACTION_TIME	1.000	.000	0	.	1.000	1.000	1.000
	ERROR	1.000	.000	0	.	1.000	1.000	1.000
TRIAL_TYPE	REACTION_TIME	1.000	.000	0	.	1.000	1.000	1.000
	ERROR	1.000	.000	0	.	1.000	1.000	1.000
TIME * TRIAL_TYPE	REACTION_TIME	1.000	.000	0	.	1.000	1.000	1.000
	ERROR	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + CONDITION
Within Subjects Design: TIME + TRIAL_TYPE + TIME * TRIAL_TYPE

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Univariate Tests for 3 x 2 Mixed ANOVA

Univariate Tests

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
TIME	REACTION_TIME	Sphericity Assumed	975608.203	1	975608.203	52.728	.000	.569	52.728	1.000
		Greenhouse-Geisser	975608.203	1.000	975608.203	52.728	.000	.569	52.728	1.000
		Huynh-Feldt	975608.203	1.000	975608.203	52.728	.000	.569	52.728	1.000
		Lower-bound	975608.203	1.000	975608.203	52.728	.000	.569	52.728	1.000
	ERROR	Sphericity Assumed	11.203	1	11.203	22.474	.000	.360	22.474	.996
		Greenhouse-Geisser	11.203	1.000	11.203	22.474	.000	.360	22.474	.996
		Huynh-Feldt	11.203	1.000	11.203	22.474	.000	.360	22.474	.996
		Lower-bound	11.203	1.000	11.203	22.474	.000	.360	22.474	.996
TIME * CONDITION	REACTION_TIME	Sphericity Assumed	132996.355	2	66498.178	3.594	.037	.152	7.188	.633
		Greenhouse-Geisser	132996.355	2.000	66498.178	3.594	.037	.152	7.188	.633
		Huynh-Feldt	132996.355	2.000	66498.178	3.594	.037	.152	7.188	.633
		Lower-bound	132996.355	2.000	66498.178	3.594	.037	.152	7.188	.633
	ERROR	Sphericity Assumed	1.124	2	.562	1.128	.334	.053	2.255	.234
		Greenhouse-Geisser	1.124	2.000	.562	1.128	.334	.053	2.255	.234
		Huynh-Feldt	1.124	2.000	.562	1.128	.334	.053	2.255	.234
		Lower-bound	1.124	2.000	.562	1.128	.334	.053	2.255	.234
Error(TIME)	REACTION_TIME	Sphericity Assumed	740112.722	40	18502.818					
		Greenhouse-Geisser	740112.722	40.000	18502.818					
		Huynh-Feldt	740112.722	40.000	18502.818					
		Lower-bound	740112.722	40.000	18502.818					
	ERROR	Sphericity Assumed	19.939	40	.498					
		Greenhouse-Geisser	19.939	40.000	.498					
		Huynh-Feldt	19.939	40.000	.498					
		Lower-bound	19.939	40.000	.498					
TRIAL_TYPE	REACTION_TIME	Sphericity Assumed	1110745.399	1	1110745.399	110.762	.000	.735	110.762	1.000
		Greenhouse-Geisser	1110745.399	1.000	1110745.399	110.762	.000	.735	110.762	1.000
		Huynh-Feldt	1110745.399	1.000	1110745.399	110.762	.000	.735	110.762	1.000
		Lower-bound	1110745.399	1.000	1110745.399	110.762	.000	.735	110.762	1.000
	ERROR	Sphericity Assumed	28.353	1	28.353	59.955	.000	.600	59.955	1.000
		Greenhouse-Geisser	28.353	1.000	28.353	59.955	.000	.600	59.955	1.000
		Huynh-Feldt	28.353	1.000	28.353	59.955	.000	.600	59.955	1.000
		Lower-bound	28.353	1.000	28.353	59.955	.000	.600	59.955	1.000
TRIAL_TYPE * CONDITION	REACTION_TIME	Sphericity Assumed	14851.348	2	7425.674	.740	.483	.036	1.481	.167
		Greenhouse-Geisser	14851.348	2.000	7425.674	.740	.483	.036	1.481	.167
		Huynh-Feldt	14851.348	2.000	7425.674	.740	.483	.036	1.481	.167
		Lower-bound	14851.348	2.000	7425.674	.740	.483	.036	1.481	.167
	ERROR	Sphericity Assumed	1.008	2	.504	1.066	.354	.051	2.131	.223
		Greenhouse-Geisser	1.008	2.000	.504	1.066	.354	.051	2.131	.223
		Huynh-Feldt	1.008	2.000	.504	1.066	.354	.051	2.131	.223
		Lower-bound	1.008	2.000	.504	1.066	.354	.051	2.131	.223
Error(TRIAL_TYPE)	REACTION_TIME	Sphericity Assumed	401127.495	40	10028.187					
		Greenhouse-Geisser	401127.495	40.000	10028.187					
		Huynh-Feldt	401127.495	40.000	10028.187					
		Lower-bound	401127.495	40.000	10028.187					
	ERROR	Sphericity Assumed	18.916	40	.473					
		Greenhouse-Geisser	18.916	40.000	.473					
		Huynh-Feldt	18.916	40.000	.473					
		Lower-bound	18.916	40.000	.473					
TIME * TRIAL_TYPE	REACTION_TIME	Sphericity Assumed	22308.130	1	22308.130	7.793	.008	.163	7.793	.778
		Greenhouse-Geisser	22308.130	1.000	22308.130	7.793	.008	.163	7.793	.778
		Huynh-Feldt	22308.130	1.000	22308.130	7.793	.008	.163	7.793	.778
		Lower-bound	22308.130	1.000	22308.130	7.793	.008	.163	7.793	.778
	ERROR	Sphericity Assumed	.609	1	.609	2.000	.165	.048	2.000	.282
		Greenhouse-Geisser	.609	1.000	.609	2.000	.165	.048	2.000	.282
		Huynh-Feldt	.609	1.000	.609	2.000	.165	.048	2.000	.282
		Lower-bound	.609	1.000	.609	2.000	.165	.048	2.000	.282
TIME * TRIAL_TYPE * CONDITION	REACTION_TIME	Sphericity Assumed	3259.780	2	1629.890	.569	.570	.028	1.139	.138
		Greenhouse-Geisser	3259.780	2.000	1629.890	.569	.570	.028	1.139	.138
		Huynh-Feldt	3259.780	2.000	1629.890	.569	.570	.028	1.139	.138
		Lower-bound	3259.780	2.000	1629.890	.569	.570	.028	1.139	.138
	ERROR	Sphericity Assumed	.677	2	.339	1.111	.339	.053	2.223	.232
		Greenhouse-Geisser	.677	2.000	.339	1.111	.339	.053	2.223	.232
		Huynh-Feldt	.677	2.000	.339	1.111	.339	.053	2.223	.232
		Lower-bound	.677	2.000	.339	1.111	.339	.053	2.223	.232
Error(TIME*TRIAL_TYPE)	REACTION_TIME	Sphericity Assumed	114506.575	40	2862.664					
		Greenhouse-Geisser	114506.575	40.000	2862.664					
		Huynh-Feldt	114506.575	40.000	2862.664					
		Lower-bound	114506.575	40.000	2862.664					
	ERROR	Sphericity Assumed	12.187	40	.305					
		Greenhouse-Geisser	12.187	40.000	.305					
		Huynh-Feldt	12.187	40.000	.305					
		Lower-bound	12.187	40.000	.305					

a. Computed using alpha = .05

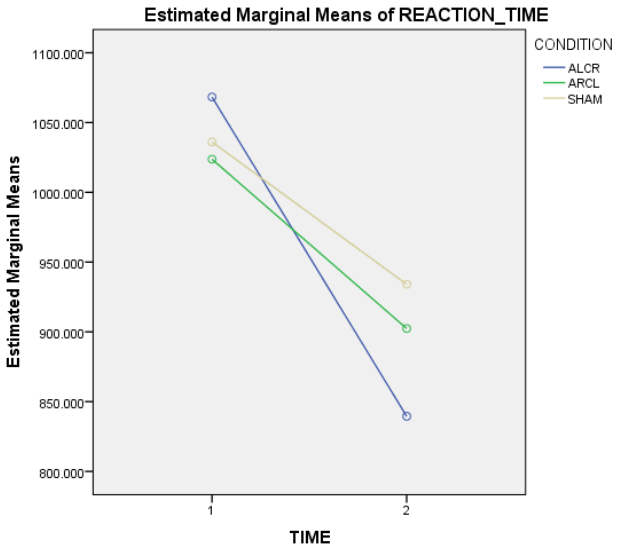
Test of Within-Subjects Contrasts for 3 x 2 Mixed ANOVA

Tests of Within-Subjects Contrasts

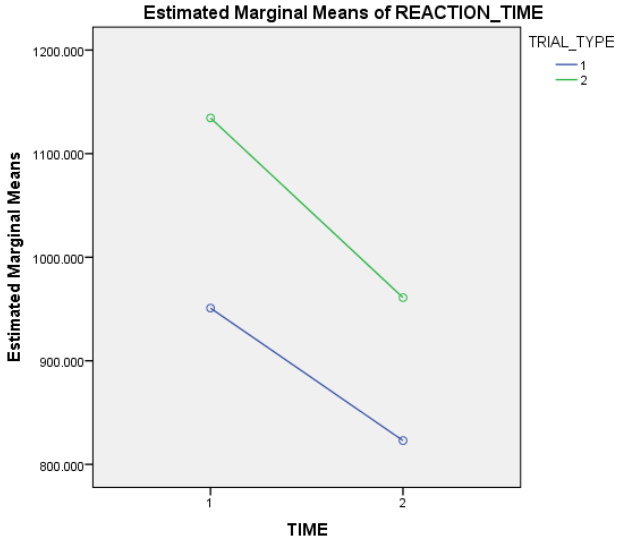
Source	Measure	TIME	TRIAL_TYPE	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
TIME	REACTION_TIME	Linear		975608.203	1	975608.203	52.728	.000	.569	52.728	1.000
	ERROR	Linear		11.203	1	11.203	22.474	.000	.360	22.474	.996
TIME * CONDITION	REACTION_TIME	Linear		132996.355	2	66498.178	3.594	.037	.152	7.188	.633
	ERROR	Linear		1.124	2	.562	1.128	.334	.053	2.255	.234
Error(TIME)	REACTION_TIME	Linear		740112.722	40	18502.818					
	ERROR	Linear		19.939	40	.498					
TRIAL_TYPE	REACTION_TIME		Linear	1110745.399	1	1110745.399	110.762	.000	.735	110.762	1.000
	ERROR		Linear	28.353	1	28.353	59.955	.000	.600	59.955	1.000
TRIAL_TYPE * CONDITION	REACTION_TIME		Linear	14851.348	2	7425.674	.740	.483	.036	1.481	.167
	ERROR		Linear	1.008	2	.504	1.066	.354	.051	2.131	.223
Error(TRIAL_TYPE)	REACTION_TIME		Linear	401127.495	40	10028.187					
	ERROR		Linear	18.916	40	.473					
TIME * TRIAL_TYPE	REACTION_TIME	Linear	Linear	22308.130	1	22308.130	7.793	.008	.163	7.793	.778
	ERROR	Linear	Linear	.609	1	.609	2.000	.165	.048	2.000	.282
TIME * TRIAL_TYPE * CONDITION	REACTION_TIME	Linear	Linear	3259.780	2	1629.890	.569	.570	.028	1.139	.138
	ERROR	Linear	Linear	.677	2	.339	1.111	.339	.053	2.223	.232
Error(TIME*TRIAL_TYPE)	REACTION_TIME	Linear	Linear	114506.575	40	2862.664					
	ERROR	Linear	Linear	12.187	40	.305					

a. Computed using alpha = .05

Supplementary Material P: Time X Condition Interaction for Reaction Time



Supplementary Material Q: Time X Trial Type Interaction for Reaction Time



Supplementary Material R: Paired Sample *t* Tests

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	RT_PRE_NEUT_ALCR	982.8786	14	124.61510	33.30479
	RT_POST_NEUT_ALCR	772.1784	14	105.12560	28.09600
Pair 2	RT_PRE_INCON_ALCL	1153.6973	14	153.40068	40.99805
	RT_POST_INCON_ALCL	906.7870	14	160.70846	42.95114
Pair 3	RT_PRE_NEUT_ARCL	944.2948	14	202.22441	54.04675
	RT_POST_NEUT_ARCL	838.4000	14	145.42155	38.86555
Pair 4	RT_PRE_INCON_ARCL	1103.1215	14	218.54045	58.40739
	RT_POST_INCON_ARCL	966.4450	14	156.46421	41.81682
Pair 5	RT_PRE_NEUT_SHAM	925.5120	15	164.85722	42.56595
	RT_POST_NEUT_SHAM	858.3537	15	228.54286	59.00951
Pair 6	RT_RE_INCON_SHAM	1146.6525	15	232.81896	60.11360
	RT_POST_INCON_SHAM	1009.7513	15	261.64256	67.55582

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	RT_PRE_NEUT_ALCR - RT_POST_NEUT_ALCR	210.70021	107.64370	28.76899	148.54859	272.85183	7.324	13	.000
Pair 2	RT_PRE_INCON_ALCL - RT_POST_INCON_ALCL	246.91034	158.87037	42.45989	155.18132	338.63936	5.815	13	.000
Pair 3	RT_PRE_NEUT_ARCL - RT_POST_NEUT_ARCL	105.89487	137.04333	36.62637	26.76840	185.02133	2.891	13	.013
Pair 4	RT_PRE_INCON_ARCL - RT_POST_INCON_ARCL	136.67650	124.44393	33.25904	64.82471	208.52829	4.109	13	.001
Pair 5	RT_PRE_NEUT_SHAM - RT_POST_NEUT_SHAM	67.15837	125.67897	32.45017	-2.44032	136.75706	2.070	14	.057
Pair 6	RT_RE_INCON_SHAM - RT_POST_INCON_SHAM	136.90116	200.69204	51.81846	25.76161	248.04071	2.642	14	.019

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	RT_NEUT_PRE	950.3049	43	164.64815	25.10861
	RT_INCONGRUENT_PRE	1134.7733	43	201.58972	30.74214
Pair 2	RT_NEUT_POST	823.8000	43	169.59553	25.86308
	RT_INCONGRUENT_POST	962.1283	43	200.56826	30.58637

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	RT_NEUT_PRE - RT_INCONGRUENT_PRE	-184.46840	123.35475	18.81142	-222.43139	-146.50541	-9.806	42	.000
Pair 2	RT_NEUT_POST - RT_INCONGRUENT_POST	-138.32825	100.99527	15.40163	-169.41001	-107.24649	-8.981	42	.000

Supplementary Material S: Statistical Consultation

STATISTICAL CONSULTATION FOR HONOURS STUDENTS 2012

Please complete this form, then email Dr Robert (Bob) Kane to make an appointment time for you and your supervisor(s).

Research Question:

The impact of Transcranial Direct Current Stimulation (tDCS) on Self-Control

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Hypotheses:

(i) Anodal tDCS over the right DLPFC and cathodal tDCS over the left DLPFC will show increased reaction time and decrease error rates on the Stroop self-control measure compared to Sham condition.

(ii) Cathodal tDCS over right DLPFC and anodal tDCS over left DLPFC will show decreased reaction time and increase error rates on the Stroop self-control measure compared to right anodal tDCS and Sham conditions.

(iii) Sham tDCS will show no difference on the pre and post Stroop self-control measure.

Sample size required based on Power Analysis:

Power calculations using G-Power (Faul, Erdfelder, Lang, & Buchner, 2007) indicate that in order to achieve the desired power of .80 at an alpha level of .05**,** 45 participants (15 in each group) will be required. A moderate (.40) effect size is anticipated.

Sampling strategy:

A sample of approximately 45 healthy individuals between the age of 18 and 35 will be recruited. Participants will be recruited from the Curtin University participation pool and via the online social media site Facebook. Participants from Curtin University will be directed to the psych research tab in the 'Undergraduate psychology everyone' section of OASIS. Curtin members that have registered with SONA will be awarded participation points for taking part in the study. Members of the non-Curtin population will be directed to a link to the same site which will contain the information sheet and exclusion criteria (See attached).

Measures (include number of factors and alpha reliability where applicable)

Stroop self control measure

The Stroop task (1935) assesses the ability to direct attention and inhibit irrelevant material. If a word is displayed in a color different from the color it actually names (for example, the word black written in yellow ink- incongrunent), participants take longer to name the word than if the word is displayed in a colour the same as the word (for example, green written in green ink- concongruent). Self-control is necessary to override the desire response to the word instead of word-colour. Previous research (Baumeister, Vohs, & Tice, 2007) has validated the use of Stroop as a measure of self-control.

Hard counting task

A hard counting task is a mental arithmatic task that generally involves counting in a sequence that might be considered difficult, such as counting down from 1000 in multiples of 7 (1000, 993, 986, 979…). In contrast an easy counting task may involve counting from 0 to 1000 in mutiple of fives (5, 10, 15, 20...). Previous studies (Tyler & Burns, 2008; Webb & Sheeran, 2003) have validated the use of a hard counting task as a reliable measure to induce self-control depletion.

Planned Analyses

Data will be analysed using a repeated measures analysis of variance (ANOVA) with tDCS condition (anodal left, anodal right, and sham) as a between groups factor and time (pre and post) as a within group factors. Assumptions tests for this analysis are: Independence, normality (assessed using Shapiro-Wilk W statistic and visual inspection of

skewness and kurtosis), homogeneity of variance (Levenne's Test of Equality of Variance), and Sphericity (assessed with Mauchly's Test of Sphericity). Statistically significant main effects will be examined first, followed by any interactions identified in the main effects**.** Finally, simple effects analysis will be used to examine interactions. For post hoc analysis, a series of Bonferroni adjusted paired samples t tests will be used to correct the alpha level of any identified interactions.

Specific Questions for Statistical Consultant.

Bob I can't seem to find psychometric properties for these measures.

Also, I just wanted to double check power analysis…

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TO BE COMPLETED BY STATISTICAL ADVISOR

□ **No changes required**

□ **The following changes are required:**

✓**The following comments should be taken on board**

Research design

You describe the following 2 x 3 mixed design.

	Pre-test	Post-test
Anodal left		
Anodal right		
Sham		

Participants will be randomly allocated to the three levels of the between-subjects factor, and then tested on the outcome variables before and after stimulation. Your outcome variables appear to be reaction time and accuracy on the Stroop self-control measure.

Hypotheses

H1: For the anodal left group, there will be a significant pre-post *decrease* in RT in conjunction with a significant pre-post *increase* in error rate on the Stroop task.

H2: For the anodal right group, there will be a significant pre-post *increase* in RT in conjunction with a significant pre-post *decrease* in error rate on the Stroop task.

H3: For the sham group, pre-post changes in RT and error rate will be negligible.

Hypothesis testing

Together, H1 – H3 predict Group x Time interactions and can therefore be tested with a couple of 2 x 3 mixed ANOVAs – one for RT and one for error rate. The ANOVAs are hypothesis-driven and can therefore be evaluated at the conventional per-test alpha-level of .05 – no Bonferroni correction required. A significant interaction should be investigated by testing the simple main effect of time within each of the three groups

Sample size (alpha = .05, power = .8)

You'll need a sufficient number of participants to detect the most participant-hungry effect, namely, the 2 x 3 interaction. You'll require 21 participants (7 in each group) in order to detect a 'large' interaction effect, 42 participants (14 in each group) for a 'moderate' interaction effect, and 246 participants (82 in each group) for a 'small' interaction effect.

References

Allen, P., & Bennett, K. (Eds.). (2010). *PASW statistics by SPSS: a practical guide: version 18.0* Melbourne, AUS: Cenage Learning Australia Pty Ltd.

Tabacknick, B., & Fidell, L. (2013). *Using Multivariate Statistics* (6th ed.). New Jersey, USA: Pearson Education