Consolidating Healthy Eating Intentions with tDCS

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ABSTRACT

tDCS
Transcranial direct-current stimulation (tDCS) has gained much recent interest by psychologists as a technique to benefit weight loss and healthy eating. An opportunity sample took part in an intention-formation task, alongside real stimulation or 'sham' stimulation. The study investigated the effect that transcranial direct current stimulation has on calorie intake in young participants. Twenty participants aged from 18-24 received either real stimulation or 'sham' stimulation (the placebo effect) and were told to watch a presentation including 20 freewill quotes as the behaviour change technique. Each participant recorded their calorie intake a pre-intervention measure on the app 'My Fitness Pal' for 7 consecutive days, it was then recorded as a post-intervention measure for a further 7 days. A 2x2 ANOVA and a t-test were used to statistically analyse the data.

Findings
Real stimulation was found to decrease calorie intake in comparison to the placebo stimulation in which calorie intake stayed the same, even increasing slightly. This was unexpected, as the hypothesis was that the placebo condition would also slightly reduce their calories due to the fact they are tracking calories and taking part in the

KEYWORDS:	TDCS	BEHAVIOUR CHANGE TECHNIQUE	FREEWILL	CALORIE INTAKE	EATING BEHAVIOUR

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Introduction

Psychologists have discovered that non-intrusive brain stimulation, such as transcranial direct current stimulation, has many health benefits ranging from reducing unhealthy food craving (Goldman et al, 2011; Foranco, 2018; Mostafavi et al, 2018; Ray et al, 2019) and aiding weight loss (Foranco et al, 2018). Many studies have investigated the effects that tDCS has on food craving and helping weight loss, but there is little research investigating the effect that using tDCS may have on calorie intake. Tasks which promote behaviour change relating to diet and exercise are a widely used technique by psychologists, therefore behaviour-change techniques will also be carried out on participants. The present study set out to investigate the possibility that using transcranial direct current stimulation and behaviour-change tasks can help participants to decrease their calorie intake.

Obesity prevalence

In many countries, a surge in obesity has gained a substantial amount of concern. If the prevalence of obesity proceeds to increase, unhealthy diet and a lack of exercise will become the main cause of preventable deaths, taking over tobacco (Mokdad et al, 2004). Individuals with obesity have an increased chance of having poor health in general. They may develop conditions which are linked to their obesity, for example, obese individuals are likely to have high rates of chronic diseases (Field et al, 2001). Obesity has even been found to be linked to chronic kidney disease (Wahba and Mak, 2007). By means of this, patients with obesity are responsible for a substantial amount of the healthcare systems, with their medical costs resulting in 30% more than the medical costs of patients of a normal, healthy weight, which therefore puts a large amount of pressure onto healthcare systems and the NHS (Withrow and Alter, 2011). If obese individuals lose weight, this will reduce the health risks which are linked to obesity, weight loss is highly encouraged for obese patients by the majority of health agencies (World Health Organisation, 2013).

In need of new techniques to ensure weight loss

Patients who are obese or overweight have few, restricted options **regarding** treatment. These options include physical activity, diet-specific counselling, and behaviour change strategies (Olson, 2017). Diets, drug therapy and weight loss programmes have not been proven to have interminable effectiveness treating weight loss in obese individuals (Fisher and Schauer, 2002). A drastic treatment option for severe obesity is surgery, which may include a gastric band or gastric bypass surgery. However, there is a substantial number of 20-40% of individuals that do not achieve a great weight loss after this surgery, the majority of patients regain the weight some years after (Adams et al, 2012). Surgery is also very expensive and can be very dangerous. Treating obesity safely, yet effectively, is extremely challenging. A considerable amount of effort and new innovations are needed to combat this public health issue (Ryder et al, 2018).

Treatment and prevention of obesity can hugely benefit from a major paradigm shift as the typical instructions to eat fewer calories and exercise are mostly ineffective and overly simplistic (Drewnoski et al, 2012). Using safe, new and established techniques such as non-invasive brain stimulation alongside behaviour change tasks may be able to provide new and effective ways to establish weight loss, which is what this report will discuss. It is of utmost importance to discover whether using tDCS alongside a behaviour-change technique can encourage a healthier lifestyle and allow individuals to decrease their calorie intake in order to improve their health.

Behaviour change techniques

Aside from brain stimulation, behaviour change techniques have been discovered to be very beneficial for people attempting to lose weight and gain a healthier lifestyle. In recent years, behaviour change techniques and theories have increased in popularity. A behaviour change technique could be defined as a small active element of an intervention (Michie et al, 2009). However, many different definitions of behaviour change techniques exist. Behaviour change techniques are effective because individuals are motivated by their desires, so they, therefore, find it easier to maintain the new behaviour which is provided by the behaviour change technique (Rothman et al, 2013). A study by Direito et al (2014) discovered that certain behaviour change techniques are very effective at modifying physical activity and diet. For example, the study found that self-monitoring using applications are 60% effective, whilst intention-formation tasks are 50% effective. The current study will be using both self-monitoring using an app and an intention formation task. This is therefore strong evidence to suggest that behaviour change techniques are useful for helping individuals change their behaviour regarding health.

Non-invasive brain stimulation

Recently, non-invasive techniques of brain stimulation have increased in popularity, with many psychologists investigating the benefits of using brain stimulation, particularly transcranial direct current stimulation. Transcranial direct current stimulation is one of the most widely used brain stimulation techniques (Hallett, 2007; Nitsche et al, 2008). The stimulation can possibly allow changing cortical excitability which is produced by applying the electrodes with different polarity to different areas on the scalp to stimulate the underlying neural tissue (Utz et al, 2010). The tDCS creates alterations in neuronal firing, which creates inhibitory or excitatory effects, which depends on the stimulation frequency (Foranco, 2018). Many psychologists favour tDCS as it is relatively cheap, has no serious side effects and is easy to administer in comparison to other types of brain stimulation such as transcranial magnetic stimulation (Nitsche and Paulus, 2011). When using tDCS, it works by applying a direct current onto the scalp. Normally the current is administered by a constant current stimulator driven by batteries, by securing electrodes of different polarities to the scalp (Iyer et al, 2005). It has been found that around 50% of the tDCS current permeates the skin and can decrease or increase the resting membrane potential of neurons in underlying areas which causes modifications in spontaneous firing (Foranco, 2018). The inhibitory and excitation effects are obtained by interchanging the locations of the electrodes amongst the right and left hemispheres (McClelland et al, 2013).

Literature review

Recent research by Foranco et al (2018) supports that neuromodulation (including tDCS) can help individuals to reduce unhealthy eating. Foranco (2018) studied research on cognitive training neuromodulation strategies which were aimed at decreasing unhealthy eating and weight, food craving and intake. It was found that stimulating the hypothalamus and dorsolateral prefrontal using tDCS provided benefits regarding a decrease in food cravings and helping people to lose weight. This study has high validity, as the quality of the studies which were reviewed were generally high therefore this study can be used as strong evidence to support that tDCS can help individuals to lose weight and reduce food cravings. However, most of the trials reviewed were short term and many of the trials were conducted using participants who were of a healthy weight. Future studies, such as this current research, should include participants who are actively trying to lose weight or may be overweight, alongside participants of a healthy weight. This would establish if the same results can be generalised to the wider population in order to gain further support that tDCS can help individuals to lose weight and reduce food cravings.

Foranco's (2018) study provided promising results of neuromodulation approaches regarding eating behaviours, the intervention of the neuromodulation used are successful when reducing participants unhealthy eating temporarily, however, it is unclear from this study what the optimal administration and training is needed to produce clinically meaningful outcomes such as sustained, long-term changes in eating a healthy diet and weight loss. It is not known whether neuromodulation techniques are useful for long-term as the majority of the studies which Foranco reviewed only analysed the impact immediately after the stimulation (Benyamini et al., 2013; Kemps et al, 2015; Ljubisavljevic et al, 2016). More research is needed to discover the optimal administration and training to add to past research.

Many studies have found similar results to Foranco (2018). Some experiments which used only one session of transcranial direct current stimulation to stimulate the dorsolateral prefrontal cortex found a positive impact upon food craving in participants, researched by food craving questionnaires (Frengi et al, 2008; Montegenegro et al, 2012; Lapenta et al, 2014). This provides strong background evidence for the current study because using tDCS on the dorsolateral prefrontal cortex may lead participants to consume fewer calories since tDCS had an effect on food craving, which is related to calorie intake. However, these studies used mostly women participants of a healthy weight. These studies, therefore, lack population validity, so it is unknown if these same results will apply to those who are overweight or males. This current research will use male and female participants, as well as overweight participants to investigate if the same results apply to different participants which will add to existing research.

Further research supports Foranco et al's (2018) findings. Mostafavi et al's (2018) meta-analysis reported that stimulating the dorsolateral prefrontal cortex with tDCS had a significant impact on energy intake and reducing food craving. However, Foranco et al (2018) suggested that using stimulation with a current intensity of 2 mA should be used in order to decrease food craving. This is strong evidence to suggest that tDCS is a powerful technique for helping change food habits and is a good background knowledge for the current study. However, an intensity of 2 mA can be uncomfortable for participants and may cause an intense tingling sensation. The current study will, therefore, use intensity of 1 mA for the tDCS to see if the impact on calorie intake is just as effective. A lower intensity in the current study is to create a more comfortable session for participants. Due to the fact that this study conducted a meta-analysis, this widely increases the power in that the results will be valid. When conducting a meta-analysis, inconsistencies are likely to be ruled out as they can be quantified and analysed. This increases the validity of the results found. The findings of Mostafavi et al (2018) has high population validity, therefore, the findings that tDCS reduces food cravings can be generalised to the wider population.

When aiming to reduce unhealthy eating habits, most researchers aim to stimulate the dorsolateral prefrontal cortex. The effects that tDCS has upon food craving may be linked to the modulation of neural circuits associated with decision-making and reward in the dorsolateral prefrontal cortex (Frengi, 2008). This can explain why the dorsolateral prefrontal cortex is the most effective location when using tDCS, it may alter decision-making with food choices in which participants make healthier food choices. The dorsolateral prefrontal cortex is also thought to represent an integral component of the structure that controls eating behaviour, in particular, the cognitive control cues which are presented in everyday life and the processing of food reward (Hollmann et al, 2013). This is good evidence to explain the importance of using tDCS on the dorsolateral prefrontal cortex when aiming to alter eating behaviour.

Goldman et al’s (2011) study also found that stimulating the dorsolateral prefrontal cortex using tDCS reduced food craving in the real stimulation condition and the sham condition. Furthermore, the participants that received real tDCS experienced a reduction in food craving a greater amount than the participants that were in the sham condition. Post hoc analyses found that stimulating the dorsolateral prefrontal cortex substantially reduced food cravings ratings for carbohydrates and sweet food, in particular for the participants that took part in real tDCS. However, a free-eating session to promote eating was used during the study, which was conducted in a laboratory setting. This study, therefore, has low ecological validity. The results found by Goldman et al (2011) may not be able to be externalised to real-life settings. To improve validity, the free-eating session should be conducted outside of a laboratory setting so it can be attributed to everyday settings. The current study will add knowledge to this research as it will allow participants to eat normally in their everyday settings and track calories onto an app. The current study will promote ecological validity and tracking calories can be attributable to everyday settings.

Although there are promising, significant findings from recent research, Grundeis et al’s (2017) study found conflicting evidence that tDCS did not alter the desire for some food cravings. These findings, therefore, do not support the notion that tDCS can alter eating behaviour. However, this study suffers from low validity as the food the participants consumed was in a laboratory setting, this cannot be applied to eating behaviours in everyday settings and may not be sufficient enough to explain the effect of tDCS upon calorie consumption.

Recent research conducted by Samdal et al (2017) discovered that using self-monitoring behaviour and setting goals is beneficial when counselling adults who are obese. This is strong evidence to support the notion behaviour change techniques are extremely effective in counselling related to eating behaviour and can benefit therapy in the real world. Samdal's (2017) study demonstrates that using behaviour change techniques have both long-term and short-term effectiveness when aiming to improve healthy eating and exercise. This shows that behaviour change tasks could be useful when aiming to decrease calorie intake.

A strength of Samdal et al's (2017) research is that a search strategy with high utility was applied, which allows researchers to find a comprehensive compilation of relevant research. Therefore, this study has high validity and provides relevant research to future studies regarding behaviour change. However, Samdal et al (2017) only recorded the long-term effects of behaviour change interventions for one year. This is a relatively brief timeframe in order to explore the long-term effects of behaviour change. After one-year patients may get accustomed to the behaviour change techniques, become bored of them and therefore they may not have as much of an effect on them anymore. More research is needed in the future to record long-term effects for longer to investigate if behaviour change techniques continue to be effective for longer than a year.

However, Michie et al (2013) found conflicting evidence. This study reported no significant relationship between behaviour change techniques impacting physical activity and improving diet. This may suggest that behaviour change techniques are not effective for all individuals aiming to improve diet and physical activity. However, Williams and French (2011) put forward results that suggest that some behaviour change techniques have benefits, but they may be more effective for some individuals more than others. The results found that specific behaviour change techniques such as giving instructions, planning actions, and reinforcing intentions towards behaviour were linked with higher levels of physical activity (Williams and French, 2011). This is strong evidence to support that using behaviour change techniques can enhance health and physical activity in an individual. This also does not prove that behaviour change techniques can alter calorie intake; only physical activity. Therefore, more research is needed to investigate if behaviour change techniques can alter eating behaviour and calorie intake.

Further research supports that behaviour change techniques are useful for increasing physical activity. French et al (2014) reported that overall behaviour-change interventions increase exercise in older adults. However, it is possible that some associations between behaviour change techniques and physical activity were completely down to chance; if this is the case it lessens the validity of the study. However, self-regulatory techniques such as prompting self-monitoring of behaviour were associated with reduced levels of exercise. This is a limitation as it shows that behaviour change techniques may not be useful when attempting to lose weight. It was concluded that the most regularly used self-regulation techniques may only be effective for younger children, and not effective for older adults. The present study will add to this research by investigating the effects that behaviour change techniques, as well as tDCS, has on the adult population.

Following reviewing the recent literature, there appears to be a gap in past research that would benefit from pursuing further research regarding tDCS and eating behaviour. Many studies that have used tDCS and behaviour-change techniques suffer from low population validity, in which they only use a narrow sample (for example, only women) which means the results cannot be replicated to the wider population. Some of the literature also suggests an uncertainty of what intensity is powerful enough to allow participants to change their eating behaviour (Mostafivi, 2018). The current study will attempt to fill this gap by using a range of different participants (for example, males and females consisting of a different weight). The current study will also use 1mA intensity in order to report if this is powerful enough for participants to reduce their calories, whilst still maintaining participants comfort. This current study will add to existing literature by using a behaviour change task in which participants view a presentation containing freewill quotes to allow participants to believe in their ability to consume fewer calories, they will also use a self-regulatory technique by tracking their calorie intake.

The present study

In this current research, tDCS will be used to stimulate the dorsolateral prefrontal cortex, as previous studies have found that stimulating these particular brain areas can provide benefits regarding weight and cravings in obese or overweight individuals (Foranco et al, 2018). During the study, each participant will receive one session of tDCS for a duration of ten minutes, whilst participating in a behaviour-change technique by viewing a presentation containing 20 freewill quotes aimed to enhance their behaviour change to ensure they eat fewer calories. This research will add greatly to previous research as there are many gaps regarding eating behaviour. tDCS is a relatively new technique, therefore, there is not an extensive amount of research relating to eating behaviour and could benefit from more research being conducted. A novel feature of the study is that in previous research tDCS has not been extensively explored for its effects upon calorie intake. If tDCS is proven to help participants to gain a healthier lifestyle by reducing calories, this will have extensive implications to the real world, including therapy, health, or even individuals who would like a new technique in order to gain a healthier lifestyle. The hypothesis is that there would be the greatest decrease in calorie intake for participants in the real tDCS condition. It was also predicted that there would be a slight decrease in calorie intake for participants in the ‘sham’ tDCS condition participating in a behaviour change technique. A significant interaction between post-intervention calorie intake and real tDCS would suggest that tDCS is beneficial towards reducing calorie intake.

Method

Design

The current experiment employed a blind, placebo-controlled, within-subjects design. The independent variable was whether the participant received real stimulation or sham stimulation, the dependent variable was the number of calories consumed post-stimulation. Extraneous variables that may occur could include demand characteristics, this will be reduced by ensuring that the participants cannot see the computer screen and will not know which condition they are in. Environmental extraneous variables will be controlled by conducting the experiment on one participant one at a time, in a quiet small room. The experiment consisted of two conditions.

A: Receive real tDCS and behaviour change technique, tracking calories for 7 days as a baseline measure and 7 days post-stimulation measure (enhanced effect).

B: Receive 'sham' tDCS and behaviour change technique, tracking calories for 7 days as a baseline measure and 7 days post-stimulation measure (placebo effect).

Participants

Twenty participants were recruited using opportunity sampling. Ten participants were involved in each condition. All participants were interested in gaining a healthier life. Although tDCS is considered safe, participants who had a history of epilepsy or eating disorders were not able to take part. There were 13 females and 7 males. Ages ranged from 18-24, with a mean of 21.15 years (SD: 1.31). Participants were recruited from Manchester Metropolitan University and the near area, within approval of the Ethics committee of the Department of Psychology, Manchester Metropolitan University.

Materials

Transcranial direct current stimulation

Transcranial direct current stimulation was used in this study for a duration of ten minutes, aimed at stimulating the dorsolateral prefrontal cortex. The equipment used was the Soterix 1x1 tDCS device. The tDCS used electrodes in which the anode was 5x5cm with a placement at F3, the cathode in which was 5x5cm and was placed at AF8, used with a current of 1mA. The sponges in which the electrodes were inserted into were soaked in saline to ensure a good contact quality to each participant.

Presentation slides

A computer was used to provide a presentation including 20 freewill quotes used as a behaviour change task. For example, 'I will persist until I succeed'. Some quotes were directly aimed at the goal of eating fewer calories, for example, 'I can eat fewer calories if I put my mind to it'. Some freewill quotes were taken from a recent article (Davis and Daw, 2018). Freewill quotes are extremely useful to use when aiding weight loss, as freewill has connections to many other cognitive and personality constructs (Feldman, 2017). Enhancing individual's motivation to believe in free will gives the participants the chance to improve their eating behaviours for themselves, without reliance on others whilst also maintaining this behaviour after the study is complete.

Fitness application

Each participant was required to download and use a mobile application called ‘My Fitness Pal’ in order to track their calories for 7 days pre-stimulation, and 7- days post-stimulation. This gave participants accessibility to easily track their calorie intake.

Procedure

Participants were given a consent form and a participant information sheet to ensure they provide their informed consent and are informed about what they are doing. The participants recorded their calorie intake for 7 consecutive days on the app ‘My Fitness Pal’. After the 7 days, each participant took part in the brain stimulation and the behaviour change task. Each participant was subjected to ten minutes of tDCS aimed at the left dorsolateral prefrontal cortex. During the stimulation, participants watched a presentation involving 20 slides which displayed one motivational free-will quote per slide, for a duration of 30 seconds each. The condition that each participant took part in was random and they did not know which condition they were in. After the stimulation, participants were given a debrief sheet and asked if they had any questions. Participants then were told to record their calories on the ‘My Fitness Pal’ app for a further 7 consecutive days to assess if the tDCS affected their calorie intake. The experiment lasted two weeks overall.

Real tDCS procedure

A single 10-minute tDCS session was conducted at 1mA intensity. (Soterix 1x1 tDCS device). The electrodes were typical sponge electrodes which were soaked in sodium chloride (1% saline solution) and placed on the scalp, with cathode location at AF8, anode location at F3 to stimulate the dorsolateral prefrontal cortex.

Sham tDCS procedure

The same placement of the anode and cathode was applied to the sham participants, however, the machine was turned onto ‘sham' mode. This provides the same amount of stimulation at first to make the participants believe they are receiving real stimulation, then the intensity wears off until it goes to zero, in which they only experienced a small electrical current.

Ethics

Participants provided their informed consent by completing a consent form. They were informed about what the study consists of and was given a participant information sheet. After the study, participants were given a debrief sheet including the researchers' contact details. The experiment did not use any personal data except for their forename, however, names of participants were kept fully anonymous by giving them a pseudonym, such as ‘Participant X'. All data collected from the ‘My Fitness Pal’ app was stored on a password protected computer only known by the researcher. Information will be retained for a minimum of three years and will be disposed of securely. To ensure anonymity is protected, any information that is shared elsewhere outside of the university will have participants' personal information such as their name removed so they cannot be recognised.

Results

Statistical analyses

The present study found that the mean calorie intake for participants before the intervention was 1,837, the standard deviation was 347.3. However, the individual number of calories varies due to the fact that there were males and females participating in the study. The recommended intake for a healthy male is 2500 calories per day. Whereas the recommended calorie intake is around 2000 calories a day for females (NHS, 2016). As these participants were already aiming to gain a healthier lifestyle, an average of 1,837 calories per day is a relatively normal calorie intake for a healthy individual. It was also found that after the stimulation, the mean value of daily intake calories consumed by the participants (real and sham) was 1,707. Participants decreased their calorie intake overall, therefore, supporting the hypothesis that transcranial direct current stimulation can help participants to decrease their calorie intake. All statistical analyses were conducted using IBM SPSS Statistics version 20.0. A 2x2 ANOVA was conducted for the analysis of the number of calories consumed by each participant, with factors for time (baseline, post-intervention) and for stimulation (real, sham). An independent samples t-test was also conducted to analyse the significance of the results.

The 2x2 ANOVA showed that the main effect of time (baseline, post-intervention) was not statistically significant, $F(1, 18) = 5.57$, $p = 0.145$. However, there was a significant interaction between stimulation (real, sham) and time (pre-intervention, post-intervention), $F(1,18) = 5.57$, $p = 0.030$, $\eta_p^2 = 0.236$. (Look in appendices table 1 to show the interaction between stimulation and time). The results strongly support the hypothesis supposing that taking part in tDCS can help participants to decrease their calorie intake.

Table 3. Mean and standard deviation calorie intake for real tDCS and sham tDCS conditions groups for the week

Descriptive Statistics

	Stimulation	Mean	Std. Deviation	N
Pre-stimulation	Real	12611.8	2894.8	10
	Sham	13109	1990.3	10
Post-stimulation	Real	10292.4	2428.67	10
	Sham	13607.6	1712.1	10

Table 3 shows the total mean of all participants for each week. Participants that received the real stimulation had an average of 1470 calories per day, (*M* = 10,292 total), in comparison to the participants in the sham condition averaging 1944 calories per day post-intervention (*M* = 13,608). This supports the hypothesis that participants that received real brain stimulation decreased their calorie intake a greater amount in comparison to participants that received sham stimulation. However, the participants that received sham stimulation slightly increased their calorie intake post-intervention, which does not support the hypothesis and may show that behaviour-change techniques and tracking calories are not sufficient enough in order to reduce calorie intake.

Figure 4: Bar chart showing the difference in total calories consumed for sham and real stimulation participants for the baseline week and post-intervention week.

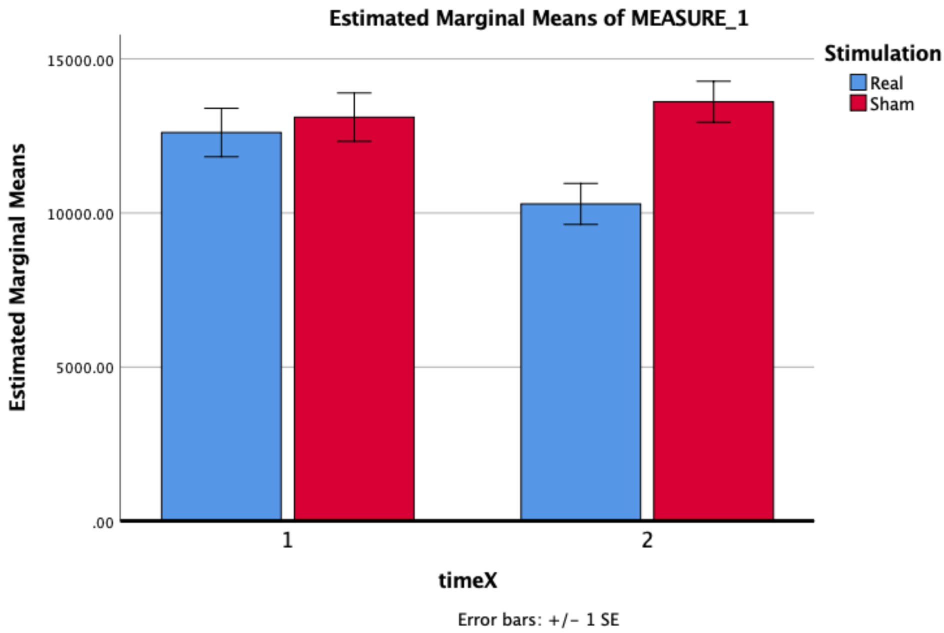

Figure 4 shows how the calorie intake of participants in the sham condition maintained the same number of calories for post-stimulation as they did pre-stimulation. The sham participants calorie intake slightly increased post-intervention which was not what the hypothesis predicted. However, the participants in the real stimulation condition considerably reduced their calories after the stimulation which supports the hypothesis that tDCS can help individuals to consume fewer calories. The error bars show an indication of error or uncertainty in measurement.

A t-test was conducted to determine whether the mean difference between pre-intervention and post-intervention calorie intake was significant. There was not a significant difference in the scores for the pre-stimulation (*M* = 12860, *SD* = 2431) and post-intervention (*M* = 11950, *SD* = 2660), $t(38) = 1.13$, $p = 0.266$, d = 0.36. This is under 0.5, therefore it has a small effect size. Cohen's d ($d = .36$) suggested a small to moderate practical significance. The results suggest that participants that took part in tDCS decreased their calorie intake, however, participants that took part in the ‘sham’ stimulation did not decrease their calorie intake. Therefore, there is a difference between conditions and real tDCS is needed to ensure that individuals reduce their calorie intake.

Overall, the results suggest that the interaction of time and stimulation was statistically significant. This supports the hypothesis that tDCS is extremely beneficial to be used in order to help participants to reduce their calories, which supports a healthy lifestyle. However, due to the fact that the participants in the 'sham' condition did not decrease their calories, this study shows that intention-formation tasks alone may not be adequate enough when aiming to consume fewer calories. This shows that tDCS may also be needed alongside behaviour change techniques to enhance effectiveness.

Discussion

The results from the present study indicate that using tDCS brain stimulation can help participants to decrease their calorie intake substantially, alongside using behaviour-change techniques that are accustomed to increase participants own belief in their free will. This finding supported the hypothesis that tDCS would help individuals to reduce their calorie intake. However, the hypothesis predicted that participants in the 'sham' condition would also reduce their calorie intake, however, they maintained the same number from pre-intervention. This suggests that behaviour-change techniques alone are not sufficient enough to allow participants to decrease calorie intake; which shows that tDCS is needed as a further technique to ensure participants can decrease their calories. The present study concurs with most previous research (Goldman et al, 2011; Foranco, 2018; Mostafavi et al, 2018; Ray et al, 2019) that tDCS can help to alter eating behaviour and reduce calorie intake.

The 2 x 2 ANOVA presented a significant interaction between stimulation (real, sham) and time (pre-intervention, post-intervention). This means that tDCS does have an effect on calorie reduction. This finding has a wide range of applications for real-world settings. A new technique to ensure weight loss is needed, tDCS could be carried out in diet counselling sessions to help individuals to lose weight. Many individuals find it extremely difficult to lose weight from exercise and dieting alone. Regular sessions of tDCS can provide a solution to individuals wanting to gain a healthier lifestyle. Using this also may help them maintain the smaller calorie intake to ensure weight loss.

Previous research suggested that tDCS is a useful technique to reduce unhealthy eating and weight, food craving and intake (Foranco, 2018; Mostafavi et al, 2018) and this was reflected in the findings of the current study. Foranco's (2018) research stimulated the dorsolateral prefrontal cortex, which is where the current study also stimulated. This shows that the dorsolateral prefrontal cortex may be the most effective location when aiming to reduce unhealthy eating and calorie intake.

This ties into past research, Frengi (2008) found that participants that had tDCS fixated food-related pictures less often, furthermore, real and sham conditions both consumed less food after both active stimulations. After the sham stimulation, exposure to real food increased craving, however, the real tDCS condition did not increase craving levels, which was shown by the visual analogue scales. This also is reflected in the results of the current study; real tDCS is more powerful when aiming to reduce unhealthy eating behaviours such as craving and large calorie intake, in Frengi et al's (2008) study and the present study, the sham condition did not receive substantial results as the real tDCS did. This strongly supports that tDCS is more effective than sham stimulation when aiming to modify participants eating behaviours such as calorie intake.

The results of the present study found that behaviour change techniques may not be effective unaccompanied by another technique, such as tDCS. This is shown as the sham participants did not decrease their calorie intake after the behaviour-change technique and after tracking calories (M = 13,608, SD = 1712). The real tDCS participants reduced their calories considerably post-intervention (M = 10292, SD = 2429). The finding of behaviour-change techniques alone being ineffective goes against findings of previous research, as Samdal et al (2018) concluded that setting goals and self-monitoring behaviour is beneficial when counselling obese and overweight adults. However, the participants used in the current study were relatively healthy participants wanting to gain a healthier lifestyle. This could show that behaviour-change techniques are not as effective for healthy participants in comparison to obese participants. This adds to previous research showing that behaviour-change techniques are more beneficial for some individuals more than others. Behaviour change techniques should be used alongside real tDCS to create maximum effectiveness.

Michie et al (2009) also reported that behaviour change techniques did not have a significant relationship with impacting physical activity and improving diet, which concurs with the current study's findings. However, French et al (2014) reported that overall behaviour-change interventions increase exercise activity in older adults (d = .014). However, self-regulatory techniques such as prompting self-monitoring of behaviour were associated with reduced levels of exercise. This concurs with the present research as calorie tracking was used as a self-regulatory technique, which may not have been effective as the 'sham' condition did not decrease their calorie intake. Therefore, the present study provides further evidence for the claim that self-regulatory techniques may only be effective for younger children, and not effective for adults. tDCS should be conducted on participants whilst participating in a behaviour-change to create maximum effectiveness.

The study by Mostafavi et al's (2018) stated that 2mA intensity should be used for tDCS to be effective when aiming to reduce food craving. The present study found that when aiming to reduce calorie intake, 1mA of intensity for 10 minutes was powerful enough for participants to reduce their calorie intake post-intervention. This may be due to the fact that reducing food craving could possibly be more difficult to control than decreasing calories, therefore needs a stronger intensity.

However, although the significant findings of tDCS being associated with a reduction of calories concur with most past research, some research found opposing results. Grundeis (2017) denied that tDCS has the ability to reduce the desire for visually presented foods. This study provides weak evidence for the results of the present study as it suggests tDCS may not be effective for calorie intake in all individuals. However, this study used only obese females, therefore the ineffective results of tDCS may only apply to this small sample of participants.

The present study has many strengths regarding methodology. The tDCS was carried out in a laboratory, therefore, this is relatively easy to replicate for future research. tDCS is a safe, non-invasive procedure which can stimulate the brain without surgery and minor side effects (for example, tingling sensation). tDCS has previously been found to have many benefits towards health such as food craving (Frengi et al, 2008; Montegenegro et al, 2012; Lapenta et al, 2014). The present study adds more knowledge to show that tDCS can also benefit individuals when aiming to reduce calories. A further strength of the present study is that there was a condition in which sham stimulation was used. This supports the notion that tDCS is extremely effective at helping participants to reduce their calorie intake, and that it did not happen by chance. This is shown as the participants receiving real stimulation reducing their calories, whereas the participants in the sham stimulation did not. This provides strong support for tDCS being the sole reason that participants reduced their calories.

Although the present study found that tDCS had a significant effect on decreasing calorie intake, there are some methodological limitations. Firstly, the sample size is relatively small (n = 20). The participants were all relatively healthy participants with no health issues, and between the ages of 18-24. Due to low population validity, the findings of the study may not be able to be extrapolated to the wider population, for example, older adults or individuals with obesity. Future research could replicate the experiment using a larger sample with a range of participants of age and weight to investigate if tDCS can help all types of participants to consume fewer calories.

Another limitation of the present study is that it only recorded short-term effects of tDCS on calorie intake. The study recorded calorie intake for 7 days post-intervention, however, it is not known whether the effects will last longer than this or if after 7 days participants may need a ‘top up’ to maintain the effectiveness of tDCS on calorie reduction. Future research could maintain calorie recording for longer than 7 days and employ tDCS if calories increase to maintain effectiveness.

The most important strength of this research is that it has great applications for therapy, tDCS could be used as an immediate application for therapy based on eating behaviour. This study is extremely useful in the real world and can be used in health settings for obese patients. As described in the introduction, obesity has a major strain on health and can cause many problems for the individuals, the health issue needs new innovations and treatments (Ryder et al, 2018). TDCS may be the answer to this substantial health issue.

Conclusion

The results from this study indicate that tDCS does reduce calorie intake when given with a behaviour-change technique. Participants that received real stimulation reduced their calories, in comparison to the sham participants that did not. It was expected that the sham participants would reduce their calorie intake slightly, as they were tracking calories and receiving the behaviour change technique. This finding is interesting and may show that behaviour-change techniques are not effective when given alone. The results from the current study and previous research suggest that tDCS has the potential to have major effects in the health industry and could be used as a possible treatment for obesity. Further research is needed to assess its potential in different populations and its long-term effect on calorie intake.

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