Modulating Affective Experience and Emotional Intelligence with Loving Kindness Meditation and Transcranial Direct Current Stimulation: A Pilot Study

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ARTICLE

Modulating affective experience and emotional intelligence with loving kindness meditation and transcranial direct current stimulation: A pilot study

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ABSTRACT
Positive emotional perceptions and healthy emotional intelligence (EI) are important for social functioning. In this study, we investigated whether loving kindness meditation (LKM) combined with anodal transcranial direct current stimulation (tDCS) would facilitate improvements in EI and changes in affective experience of visual stimuli. LKM has been shown to increase positive emotional experiences and we hypothesized that tDCS could enhance these effects. Eighty-seven undergraduates were randomly assigned to 30 minutes of LKM or a relaxation control recording with anodal tDCS applied to the left dorsolateral prefrontal cortex (left dlPFC) or right temporoparietal junction (right TPJ) at 0.1 or 2.0 milliamps. The primary outcomes were self-reported affect ratings of images from the International Affective Picture System and EI as measured by the Mayer, Salovey and Caruso Emotional Intelligence Test. Results indicated no effects of training on EI, and no main effects of LKM, electrode placement, or tDCS current strength on affect ratings. There was a significant interaction of electrode placement by meditation condition (p = 0.001), such that those assigned to LKM and right TPJ tDCS, regardless of current strength, rated neutral and positive images more positively after training. Results suggest that LKM may enhance positive affective experience.

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KEYWORDS
Loving kindness meditation; transcranial direct current stimulation; emotional intelligence; affective experience; positive affect

Introduction

Emotional intelligence (EI) involves the abilities to recognize, decode, attribute, and react to the emotional states of others (Salovey & Mayer, 1990). It has been argued that EI and its substrates enable the complex social interactions that facilitate group living and cooperation which have been argued to be key players in mankind's evolutionary success (Krebs, 2008; Wilson, 2013). On the other hand, impaired EI and interpersonal interactions are hallmarks of criminal offenders, bullies, youth with conduct disorder, and individuals with autism (Baron-Cohen & Wheelwright, 2004; de Wied, van Boxtel, Matthys, & Meeus, 2012; Domes, Hollerbach, Vohs, Mokros, & Habermeyer, 2013; Hoffman, 1987; Kokkinos & Kipritsi, 2012). Investigating how EI and the abilities that underlie it might be enhanced is therefore relevant to individual and societal well-being, and drove us to explore one potential method of doing so.

Enhancing emotional intelligence via positive affective experience

Increases in positive affective states predict EI-related improvements and prosocial behaviors (Fredrickson, 2013). Likewise, a higher ratio of positive to negative events among college roommates predict greater positive affect sharing between them, which then predicts greater depth and complexity of understanding between individuals (Waugh & Fredrickson, 2006). A tendency toward positive emotions (e.g., happiness) is shown to engender greater trust (Dunn & Schweitzer, 2005) and positive affect predicts reductions in intergroup differences and greater inclusiveness (Dovidio, Gaertner, Isen, & Lowrance, 1995; Johnson & Fredrickson, 2005). One study found a positive mood manipulation produced greater perspective taking and compassionate responding, as compared to neutral or negative mood manipulations, in a task evaluating the

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distress of a culturally dissimilar other (Nelson, 2009). These studies point to an overall increase in prosocial behaviors with positive emotional shifts. Therefore, modulation of EI might be accomplished via manipulations to increase positive affect and/or positive perceptions of external stimuli.

Enhancing emotional intelligence via mindfulness

Mindfulness interventions have long been employed as both a treatment for clinical disorders and for positive growth among healthy individuals in non-clinical settings (Beddoe & Murphy, 2004; Birnie, Speca, & Carlson, 2010; Block-Lerner, Adair, Plumb, Rhatigan, & Orsillo, 2007). Loving kindness meditation (LKM) is a practice that provides explicit instructions for the practitioner to imagine kind sentiments and positive emotions towards loved ones, strangers, the self, and those one has difficulties with in a step-wise and non-judgmental process. The practice begins by associating positive emotions and well wishes to significant others, then to others with whom the person experiences difficulties, and finally to all sentient beings. Weng and colleagues (2013) examined the effects of two weeks of daily LKM on altruistic behavior and found that relative to controls, those who listened to the LKM recordings increased their prioritization of the well-being of another over the self.

Other studies have linked LKM with changes in social-connectedness, increases in positive affect, and greater feelings of warmth for others and the self (Kok & Singer, 2017). Specifically, studies evince positive changes in both self-affect (i.e., how the individual feels; Klimecki, Leiberg, Lamm, & Singer, 2012; Kok & Singer, 2017), and perceptual affect (i.e., how the individual feels about external stimuli; Hutcherson, Seppala, & Gross, 2008). For example, Hutcherson and colleagues (2008) found that after LKM, participants experienced greater positivity and less negativity, and felt more positively towards strangers than they had at baseline. A 1-day LKM training compared to memory training resulted in greater ratings of empathy for distressed others, increases in experienced positive affect, and evidence of neuroplastic changes, indicating that mindfulness effects may be modulated at the neural level (Klimecki et al., 2012). LKM-based practices have also increased accuracy when reading emotions in facial expressions along with fMRI signal from known regions of interest (ROIs) related to empathic processing (Mascaro, Rilling, Tenzin Negi, & Raison, 2012). For these reasons, the current project endeavored to study the effects of LKM on EI and affect ratings of images showing a spectrum of emotional content and further investigate whether the gains of LKM could be modulated by neurostimulation.

Enhancing emotional intelligence via neurostimulation

Transcranial direct current stimulation (tDCS) may also be useful for manipulation of positive affect. TDCS involves the transmission of a weak electric current between two rubber-bound electrodes to modulate neuronal excitability in the brain (Liebetanz, Nitsche, Tergau, & Paulus, 2002; Stagg & Nitsche, 2011; Trumbo et al., 2016). The effects of tDCS on learning a variety of tasks have been known to last between 60 and 120 minutes after a single stimulation period ends (Coffman, Clark, & Parasuraman, 2014; Paulus, Antal, & Nitsche, 2012). Anodal current applied to the right temporoparietal junction (right TPJ; a region implicated in empathic-related processes) has been associated with enhancements of imitation ability and social cognition (Santiesteban, Banissy, Catmur, & Bird, 2012). There is also initial evidence that tDCS combined with a brief meditation practice might improve both mood and mindful awareness (Badran et al., 2017).

Current study

Consistent with the findings of Santiesteban and colleagues (2012), the right temporoparietal junction (right TPJ) has been implicated in attributing mental states to others in a meta-analysis of over 200 fMRI studies (Saxe & Wexler, 2005; Van Overwalle, 2009) and showed greater functional activation in LKM experts compared to novices during exposure to emotional sounds (Lutz, Brefczynski-Lewis, Johnstone, & Davidson, 2008). Additionally, temporoparietal regions are cited as a potential meeting point of bottom up and top-down circuits supporting a variety of EI related behaviors (Chiavarino, Apperly, & Humphreys, 2012; Decety & Lamm, 2006, 2007). Alternatively, the dorsolateral prefrontal cortex (dlPFC) is believed to play a role in the evaluation of affective content (Amting, Greening, & Mitchell, 2010; Ochsner, Bunge, Gross, & Gabrieli, 2002) as well as cognitive attentiveness to emotional stimuli and reappraisal (Kim & Hamann, 2007). Anodal stimulation to the left dlPFC corresponds with reductions in negative ratings of visual stimuli, which may prove useful to promote the positivity bias associated with prosocial behavior (Peña-Gómez, Vidal-Piñeiro, Clemente, Pascual-Leone, & Bartrés-Faz, 2011). Individuals showing impairments identifying emotions within the self also showed hypo-function of the left dlPFC (Moriguchi et al., 2007). The dlPFC demonstrates differential patterns of activation/deactivation for expert vs. novice meditators, during attentional shifts toward the self (Dickenson, Berkman, Arch, & Lieberman, 2012; Farb et al., 2007; Manna et al., 2010), and a review of stimulation studies found the left dlPFC specifically relates to positive shifts in affective experience and could represent a critical region of interest (ROI) for positively-orienting, top-down emotional modulation (Mondino, Thiffault, & Fecteau, 2015). Therefore, we believed targeting either of these ROIs (left dlPFC or right TPJ) may facilitate EI and prosocial behavior if paired with a positively-oriented practice in self-other processing.

Our motivations were to use LKM as a means of "exercising" EI and related processes through mindfulness and modulate this effect by applying anodal tDCS current to the right TPJ (to stimulate empathic-related processes directly) or the left dlPFC (to stimulate change in regions of interest involved in considerations of emotional content). Potentially, both stimulation protocols could provide benefits during LKM and enhance the effects of mindfulness practice on improved evaluation of visual, emotional stimuli. We hypothesized that LKM would result in greater EI and potential shifts in affect evaluations of IAPS stimuli. We also hypothesized that tDCS would facilitate the gains of a 30-minute meditation and tested competing neural targets for stimulation (right TPJ and left dlPFC).

Methods

This study used a 2 x 2 x 2 randomized, controlled design to investigate the impact of tDCS current (Active 2.0 mA x Sham 0.1 mA), meditation (LKM x control), and electrode placement (left dlPFC x right TPJ) on a measure of affective experience (subjective reports while viewing the International Affective Picture System [IAPS], Ito, Cacioppo, & Lang, 1998) and on a measure of emotional intelligence (Mayer, Salovey, & Caruso, 2006; Mayer Salovey & Caruso Emotional Intelligence Test [MSCEIT]).

Participants

Subjects were 87 undergraduates from the University of New Mexico (age 18–46 Mean (SD) = 20.16 (4.34), 63 females, 24 males, 6 Asian, 3 Black, 37 Hispanic, and 23 White), recruited primarily from psychology courses in which students received credit for research participation. All procedures were approved and monitored by the local institutional review board. Subjects were assigned to one of 8 groups, matched for sex, to the independent conditions: tDCS current (0.1 or 2.0 mA), electrode placement (left dlPFC or right TPJ), and meditation condition (Control or LKM) via Excel. Demographic variables for each can be found in Table 1.

Table 1. Demographics by condition.

	Electrode Placement		Meditation Condition		tDCS Current	
Variables	CP6	F3	LKM	Control	2.0mA	0.1mA
Female	33	30	33	30	33	30
Male	11	13	13	11	11	13
Age 18–20	39	34	38	35	38	35
Age 21–46	5	9	8	6	6	8
Hispanic	21	16	20	17	22	15
White	11	12	16	7	12	11
Asian	2	4	3	3	3	3
Black	2	1	1	2	1	2

Ethnicity may not be reported for all subjects as anyone could opt out of declaring this answer.

Participants were excluded from the study if they reported regular (weekly or more) meditation practice, a history of any psychiatric or neurological illnesses, brain injuries, metallic implants, prior neurostimulation experience, and/or allergies to any of the testing materials. All participants were right-handed and had healthy/corrected-to-normal vision.

Measures

The IAPS is a standardized set of stimuli with known and validated emotional content (Lang, Bradley, & Cuthbert, 2008). The Self-Assessment Manikin (SAM) scale, (Figure 1) is traditionally used to evaluate the IAPS images using a non-gendered figure to represent a range of choices numerically scaled from 1 to 9 on affect (negative to positive affective content) and arousal (calmness to non-affective excitement). Because effects on arousal are not of interest, the discussion will be isolated to IAPS affect scores. Ratings on the SAM scale show sensitivity to differences in emotional states across a wide range of studies (Backs, da Silva, & Han, 2005; Bradley, Codispoti, Sabatinelli, & Lang, 2001; Grühn & Scheibe, 2008; Keil & Freund, 2009). We defined images as negative if scored in the 1–3 range on affect, neutral in the 4–6 range on affect, and positive in the 7–9 range. Likewise, images were scored as low arousal if rated in the 1–4.5 range or high arousal if 4.6–9 on the IAPS arousal scale. We chose a set of 60 images matched on affect and arousal: 10 low arousal/negative, 10 low arousal/positive, 10 high arousal/negative, 10 high arousal/positive, and 20 neutral. Images were randomized across participants but held constant from pre to post meditation. Higher scores on the affect scale denote greater positivity. Tasks were programmed using the E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) with image presentation for 3

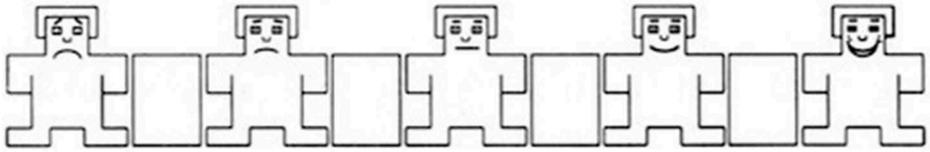

Figure 1.

Note: Self-Assessment Manikin or SAM Scale showing high negativity on the left to high positivity on the right. IAPS images used were isolated to: 2590, 2745.1, 2272, 2230, 2191, 2691, 2345, 2491, 2102, 2299, 2000, 2235, 2382, 2580, 2301, 2480, 2304, 2579, 2703, 2340, 2308, 2216, 2683, 2385, 2440, 2312, 2620, 2710, 2217, 2345.1, 2399, 2396, 2271, 2347, 1340, 2594, 2717, 2457, 2374, 2511, 2141, 2488, 2370, 2357, 2722, 2593, 2039, 1710, 2393, 2303, 2346, 2107, 2053, 2352.1, 2495, 2501, 2038, 2598, 2045, 2104.

seconds followed by an unlimited window in which to rate the image on affect, and arousal using numerical keys corresponding to values on the SAM scale.

The MSCEIT (Mayer et al., 2006) is a behavioral measure that was designed to assess EI. It breaks EI down into two categories, experiential and strategic, which are further decomposed into Perceiving Emotions (accurately recognizing emotional content) and Facilitating Thought (the ability to utilize emotional awareness for other endeavors), and Understanding Emotions (the ability to comprehend and interpret the changing of emotions across contexts) and Managing Emotions (the ability to affect or modulate emotions in the self and others), respectively. Each of the four sections can be scored individually or aggregated for a total EI score (Mayer et al., 2006), which has excellent test-retest reliability ($r(59) = .86$, $p < .001$, Brackett & Mayer, 2003) and a split-half reliability of r = 0.91 according to the technical manual (Mayer et al., 2006). The MSCEIT was scored on this study according to the experts' rubric of correct answers. Higher scores on the MSCEIT indicate greater EI (Mayer et al., 2006).

To control for potential personality-related confounders, we also examined personality traits as measured via the Big Five Inventory (BFI; John & Srivastava, 1999). The BFI traditionally measures five dimensions of personality: Extraversion vs. Introversion, Agreeableness vs. Antagonism, Conscientiousness vs. Lack of Direction, Neurotiscism vs. Emotional Stability, and Openness vs. "Closedness to Experience." Personality traits have been shown to be correlated with EI (Barrio, Aluja, & García, 2004) and trait mindfulness (Giluk, 2009), thus we included the BFI to control for potential confounding effects of personality traits.

Training and stimulation conditions

The LKM manipulation used a recording from: "Guided Loving Kindness (Metta) Meditation with Sharon Salzberg" (available at http://www.dharma.org/resources/audio#guided, last accessed 28 June 2017). The LKM recording instructed participants to relax and direct positive emotion and intention toward the self and a variety of others. Phrases such as "May I be happy, may I be healthy, may I be free from danger, may I live with ease…" were used to guide participants. Participants were instructed to apply this mantra first to themselves, then to a significant other, a general acquaintance, someone for whom feeling positive connection was a challenge, then strangers, and all lifeforms. The guided meditation continued for approximately 30 minutes in a private testing room with lighting determined by participant preferences.

The control condition used a combination of recordings matched for time with the LKM recording and was derived from the "Reflection for Resilience and Stress Busters" podcasts from the Centers for Creative Leadership (available at https://www.ccl.org/multimedia/podcast/reflection-for-resilience-2/, last accessed 28 June 2017, see also Center for Creative Leadership, n.d. a, n.d.b). The recordings (either LKM or control) were presented on lab testing computers with volume determined by participant preferences while tDCS was administered using an ActivadoseII Iontophoresis Delivery Unit and two saline-soaked, 5×5 cm^2 sponge electrodes. Electrodes were placed after being measured for each participant according to the 10/20 system: the left dlPFC electrode was placed at location F3, and the right TPJ electrode was placed at location CP6. The modeling of 2.0 mA/active current at the right TPJ site is shown in Figure 2 and modeling for the left dlPFC in Figure 3 with similar modeling suggesting little to no current getting into the cortex using 0.1 mA of stimulation.

Procedure

Pre-manipulation

Participants were recruited through flyers, classroom visits, and online advertising After providing informed, written consent, participants completed a computerized version of the BFI and baseline IAPS assessment using an LED monitor approximately 60 cm from the

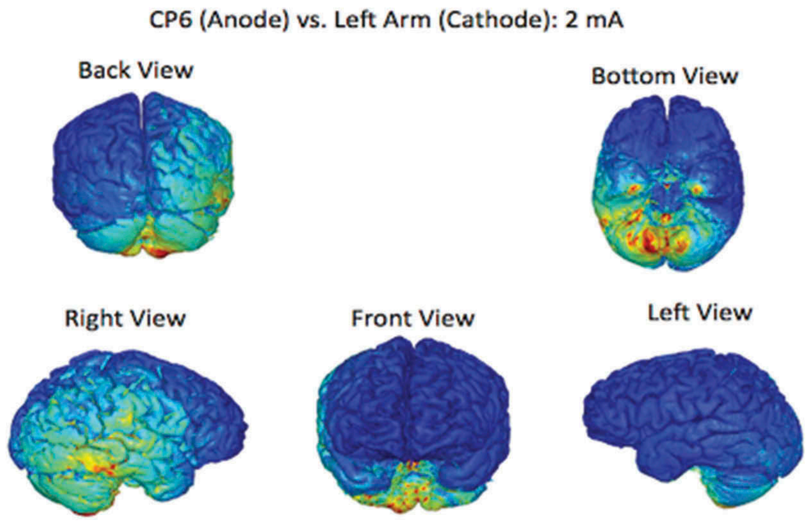

Figure 2.

Note: This figure shows modeling of 2.0mA anodal current at a CP6 electrode placement suggesting contact for temporal, temporoparietal, occipital, and cerebellar regions.

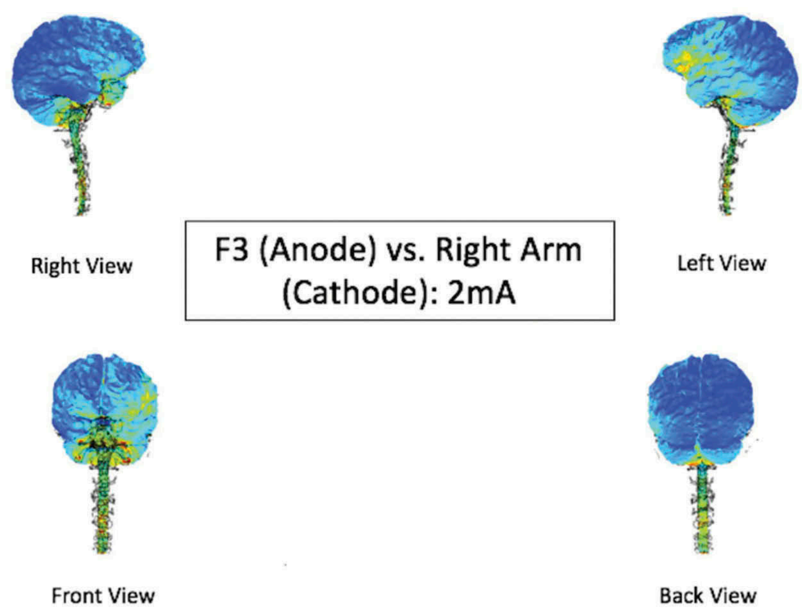

Figure 3.

Note: This figure shows 2.0mA current modeling at the L dlPFC placement (F3) suggesting contact for the dlPFC, temporal regions, limbic regions, cerebellum, and brainstem.

subject. Following that, participants answered two free response questions in an online questionnaire. They were asked, "Which images do you remember?" and "why?"

tDCS preparation

After completing baseline measures, a unique measurement for the electrode placement (left dlPFC or right TPJ) was calculated in Excel for every participant using tDCS electrodes positioned according to the 10/20 system. The cathode was placed on the contralateral tricep to avoid bias arising from cephalic placement of electrodes with opposite polarity. Both electrode sites were sanitized with alcohol swabs prior to application.

During the set-up of tDCS, participants were directed to read a briefing on LKM to familiarize themselves with the practice. Control recording participants were not given a briefing. In order to execute a double-blind procedure and run multiple participants simultaneously, two or more research assistants (RAs) were

Table 2. IAPS between-subjects model valance results: main effects and interactions.

Variables	Groups (1 v 2)	M_1 (SE)	M_2 (SE)	F	p	d	N_1	N_2
Current	(2.0mA v 0.1mA)	5.55 (0.04)	5.57 (0.04)	0.108	0.744	−0.05	44	43
Electrode Placement	(right TPJ v. dlPFC)	5.60 (0.04)	5.52 (0.04)	1.607	0.209	0.41	43	44
Meditation	(LKM v. Control)	5.61 (0.04)	5.51 (0.04)	2.529	0.116	0.48	46	41
Electrode Placement* Meditation	All Groups	N/A	N/A	10.929	0.001**	N/A	87	87
Current*Electrode Placement*Meditation	All Groups	N/A	N/A	3.128	0.081	N/A	87	87

*Significant at p < 0.05; **Significant at p < 0.01; ***Significant at p < 0.001.

Table 3. IAPS between-subjects model valance results: contrasts within interaction of electrode placement and meditation.

Variables	M_1 (SE)	M_2 (SE)	p	d	N_1	N_2
Within right TPJ: LKM > Control	5.75 (0.061)	5.45 (0.06)	<0.001***	1.06	22	22
Within dlPFC: LKM<Control	5.47 (0.058)	5.58 (0.067)	0.230	−0.38	24	19
Within LKM: right TPJ > dlPFC	5.75 (0.061)	5.47 (0.058)	0.001**	0.98	22	24
Within Control: right TPJ<dlPFC	5.45 (0.06)	5.58 (0.067)	0.164	−0.45	22	19

*Significant at p < 0.05; **Significant at p < 0.01; ***Significant at p < 0.001.

on staff during every experimental session. The first (blinded) RA would consent a participant, explain all experimental procedures, and set-up the tDCS placement. The second (unblinded) RA would then set the tDCS current settings for the participant's randomized condition (0.1 mA or 2.0 mA) and re-blind the tDCS system. The first (blinded) RA would continue the experimental procedures, thus the primary RA interacting with the participant and the participants themselves remained blinded to the tDCS current settings throughout the experiment.

tDCS-recording manipulation

Following the initiation of current and before the beginning of the recording, we initiated sensation checks 1 minute after stimulation began and again after a total of 5 minutes. Each participant was asked for their sensations on a 1–10 scale using three dimensions: 1) itching, 2) heat/burning, and 3) tingling and allowing for additional written comments as well. Participants were instructed to rate sensations at a 7 or above if stimulation was intolerable, and that stimulation would be ended if so. Volume was set to a comfortable and audible level for each participant prior to listening to the recordings. After the second sensation rating, the researcher performed a volume check on the recording and ensured participant comfort in the testing room before allowing him/her to listen to the recording.

Post manipulation

At the conclusion of the 30-minute recording, the participants completed the posttest IAPS task, free response questions, and the MSCEIT. All participants were debriefed at the end of the experiment.

Statistical analyses

Independent variables included tDCS current (0.1mA vs 2.0mA), meditation condition (LKM vs. Control), electrode placement (dlPFC vs. right TPJ) and IAPS image type at 5 levels (high arousal/negative, low arousal/negative, neutral, low arousal/positive, high arousal/positive). We used a repeated measures analysis of covariance (RM ANCOVA) model covarying baseline mean scores on the IAPS at each level of image type to test for group differences on affect ratings in response to the IAPS at post-test. Covariates only interacted with posttest affect scores by IAPS image type in the model. Sensitivity analyses showed that age, sex, and BFI scores did not significantly alter the effects of experimental conditions on the IAPS affect ratings or EI total score on the MSCEIT, therefore we report results with covariates excluded. Results averaging over image type are reported in Tables 2 and 3 while results per each image type are shown in Tables 4, 5, and 6. Simple contrasts of each image type against the neutral image condition were tested within this model as well. Data from the MSCEIT were analyzed using ANCOVA with sensitivity analyses including age, sex, and BFI scores as covariates. The MSCEIT was administered at post-intervention only, given that the MSCEIT is not traditionally used as a pre-post instrument.

Results

Preliminary data screening and sensation ratings

The final sample size was N = 87 for the analyses reported. Preliminary data checking revealed four individuals who were outliers as indicated by scores greater than three standard deviations away from the mean.

Table 4. IAPS valance results omnibus RM ANCOVA adding image type as within-subjects factor.

Variables	F	p	N_1	N_2
ImageType*Current	0.322	0.863	44	43
ImageType*Electrode Placement	0.592	0.670	43	44
ImageType*Meditation	0.594	0.668	46	41
ImageType*Current* Electrode Placement	2.659	0.04*	87	
(Simple Contrast: Low Arousal/Neg – Neutral)	0.898	0.078	87	
ImageType*Current* Meditation	2.197	0.078	87	
(Simple Contrast: Low Arousal/Pos – Neutral)	1.619	0.007	87	
ImageType*Electrode Placement* Meditation	3.234	0.017*	87	
ImageType*Current *Electrode Placement *Meditation	1.517	0.206	87	

*Significant at $p < 0.05$; **Significant at $p < 0.01$; ***Significant at $p < 0.001$. This table shows that by accounting for the affect of IAPS images (presented as a within-subjects variable in the model) reveals a more detailed profile of results, most of which survive Bonferroni correction (2 comparisons) for testing a more complex model on the same dependent variable (IAPS affect ratings). While the 4-way interaction did not reach significance, there is evidence for the 3-way interactions. The interaction of image type*current*electrode placement is significant but none of the pairwise contrasts within this interaction reach significance. Although image type*current*meditation is marginal, within-subjects simple contrasts revealed that there were group differences on the contrasts of low arousal/positive and neutral affect ratings, ultimately suggesting group differences on, neutral, low arousal/positive affect ratings or both. This is evinced by the image type for pos-neutral*current*meditation interaction reaching significance at $p = 0.007$. Lastly, the interaction of image type*electrode placement*meditation reaches significance which mimics the effect of the between-subjects model on aggregated affect scores but now additionally shows that group differences are further differentiated by the affect of the IAPS images.

Table 5. IAPS valance results: contrasts within interaction of electrode placement*meditation per image type.

Variables	M_1 (SE)	M_2 (SE)	p	d	N_1	N_2
Neutral Images						
Within right TPJ: LKM > Control	6.056 (0.074)	5.724 (0.073)	0.002**	0.96	22	22
Within dlPFC: LKM < Control	5.663 (0.07)	5.864 (0.081)	0.067	−0.58	24	19
Within LKM: right TPJ > dlPFC	6.056 (0.074)	5.663 (0.07)	<0.001***	1.14	22	24
Within Control: right TPJ < dlPFC	5.724 (0.073)	5.864 (0.081)	0.208	−0.40	22	19
Low Arousal Positive Images						
Within right TPJ: LKM > Control	7.424 (0.109)	6.914 (0.108)	0.001**	1.00	22	22
Within dlPFC: LKM < Control	7.043 (0.104)	7.355 (0.119)	0.055	−0.61	24	19
Within LKM: right TPJ > dlPFC	7.424 (0.109)	7.043 (0.104)	0.014*	0.75	22	24
Within Control: right TPJ < dlPFC	6.914 (0.108)	7.355 (0.119)	0.008**	−0.86	22	19
High Arousal Positive Images						
Within right TPJ: LKM > Control	8.005 (0.104)	7.645 (0.104)	0.017*	0.74	22	22
Within dlPFC: LKM > Control	7.845 (0.1)	7.771 (0.114)	0.636	0.15	24	19
Within LKM: right TPJ > dlPFC	8.005 (0.104)	7.845 (0.1)	0.274	0.33	22	24
Within Control: right TPJ < dlPFC	7.645 (0.104)	7.771 (0.114)	0.421	−0.26	22	19
Low Arousal Negative Images						
Within right TPJ: LKM > Control	4.568 (0.118)	4.321 (0.117)	0.142	0.45	22	22
Within dlPFC: LKM < Control	4.244 (0.112)	4.288 (0.129)	0.799	−0.08	24	19
Within LKM: right TPJ > dlPFC	4.568 (0.118)	4.244 (0.112)	0.052	0.59	22	24
Within Control: right TPJ > dlPFC	4.321 (0.117)	4.288 (0.129)	0.853	0.06	22	19
High Arousal Negative Images						
Within right TPJ: LKM > Control	2.718 (0.120)	2.646 (0.119)	0.672	0.13	22	22
Within dlPFC: LKM < Control	2.554 (0.115)	2.610 (0.132)	0.751	−0.1	24	19
Within LKM: right TPJ > dlPFC	2.718 (0.120)	2.554 (0.115)	0.332	0.29	22	24
Within Control: right TPJ > dlPFC	2.646 (0.119)	2.610 (0.132)	0.845	0.06	22	19

*Significant at $p < 0.05$; **Significant at $p < 0.01$; ***Significant at $p < 0.001$. This table shows the pairwise contrasts of electrode placement within levels of meditation and contrasts of meditation group within each electrode placement group. The omnibus electrode placement*meditation interaction with IAPS image type as within was significant ($p = 0.017$) prompting tests of these contrasts. Individuals who practiced LKM with an right TPJ electrode (regardless of current strength) show significantly higher (more positive) affect ratings for positive and neutral images. A similar trend exists for low arousal/negative images but does not reach significance.

Table 6. IAPS valance results: contrasts within interaction of current*electrode placement per image type.

Variables	M_1 (SE)	M_2 (SE)	p	d	N_1	N_2
Neutral Images						
Within Sham: right TPJ > dlPFC	5.895 (0.073)	5.828 (0.076)	0.526	0.19	22	21
Within Active: right TPJ > dlPFC	5.886 (0.074)	5.699 (0.075)	0.083	0.54	22	22
Within left dlPFC: Active < Sham	5.699 (0.075)	5.828 (0.076)	0.235	−0.37	22	21
Within right TPJ: Active < Sham	5.886 (0.074)	5.895 (0.073)	0.919	−0.03	22	22
Low Arousal Positive Images						
Within Sham: right TPJ > dlPFC	7.218 (0.107)	7.158 (0.112)	0.155	0.12	22	21
Within Active: right TPJ < dlPFC	7.120 (0.109)	7.240 (0.111)	0.151	−0.23	22	22
Within left dlPFC: Active > Sham	7.240 (0.111)	7.158 (0.112)	0.606	0.16	22	21
Within right TPJ: Active < Sham	7.120 (0.109)	7.218 (0.107)	0.527	−0.19	22	22
High Arousal Positive Images						
Within Sham: right TPJ < dlPFC	7.816 (0.103)	7.871 (0.107)	0.149	−0.11	22	21
Within Active: right TPJ > dlPFC	7.834 (0.105)	7.746 (0.107)	0.151	0.18	22	22
Within left dlPFC: Active < Sham	7.746 (0.107)	7.871 (0.107)	0.417	−0.25	22	21
Within right TPJ: Active > Sham	7.834 (0.105)	7.816 (0.103)	0.903	0.04	22	22
Low Arousal Negative Images						
Within Sham: right TPJ > dlPFC	4.511 (0.116)	4.184 (0.121)	0.055	0.60	22	21
Within Active: right TPJ > dlPFC	4.377 (0.118)	4.349 (0.121)	0.866	0.05	22	22
Within left dlPFC: Active > Sham	4.349 (0.121)	4.184 (0.121)	0.344	0.33	22	21
Within right TPJ: Active < Sham	4.377 (0.118)	4.511 (0.116)	0.422	−0.24	22	22
High Arousal Negative Images						
Within Sham: right TPJ > dlPFC	2.673 (0.119)	2.578 (0.124)	0.172	0.17	22	21
Within Active: right TPJ > dlPFC	2.690 (0.121)	2.586 (0.123)	0.174	0.18	22	22
Within left dlPFC: Active > Sham	2.586 (0.123)	2.578 (0.124)	0.962	0.01	22	21
Within right TPJ: Active > Sham	2.690 (0.121)	2.673 (0.119)	0.919	0.03	22	22

*Significant at $p < 0.05$; **Significant at $p < 0.01$; ***Significant at $p < 0.001$. This table shows the pairwise contrasts of electrode placement within levels of current strength. While the omnibus Current*Electrode Placement was significant using Image Type as within ($p = 0.04$), these contrasts do not reach significance. The means indicate, however, that any current paired with an right TPJ anode produces the most positive scores on affect for all image types except low arousal/positive.

These individuals were removed from all analyses. With respect to the sensation ratings, compared to the sham group (0.1 mA), the active group (2.0 mA) showed more itching ($F(1,86) = 44.76$; $p < 0.001$ vs. sham), heat ($F(1,86) = 56.05$; $p < 0.001$ vs. sham), and tingling ($F(1,86) = 12.92$; $p = 0.001$ vs. sham) however there were no differences on sensations due to electrode placement or meditation condition (all $p > 0.05$) suggesting neither electrode placement nor meditation practice contributed to greater stimulation-related discomfort. Although affect, arousal, and dominance scales were measured in the present study, only affect was relevant to the research question and therefore is the only IAPS variable reported.

IAPS affect results

We conducted a 5 × 2 × 2 × 2 RM ANCOVA testing the between-groups model at every level of IAPS image type (high arousal/negative, low arousal/negative, neutral, low arousal/positive, high arousal/positive). For the between-subjects model (averaging over IAPS image type), main effects of electrode placement ($F(1,85) = 1.607$, $p = 0.209$, Cohen's d = 0.41, Table 2), tDCS current ($F(1,85) = 0.108$, $p = 0.744$, Cohen's d = −0.05, Table 2), and meditation ($F(1,85) = 2.529$, $p = 0.116$, Cohen's d = 0.48, Table 2) were not significant. The two-way interaction of electrode placement*meditation was significant ($F(1,83) = 10.93$,

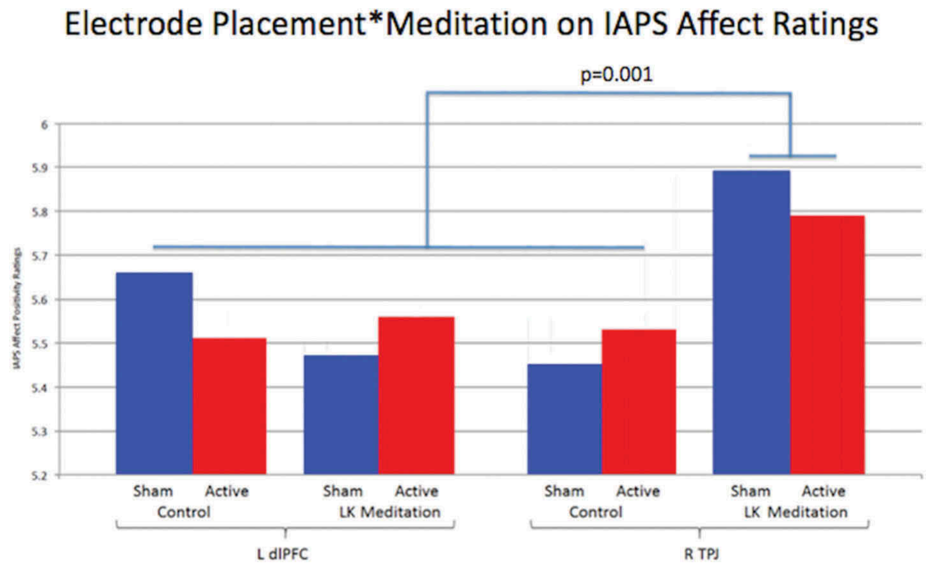

Figure 4.

Note: Bar Graph showing the omnibus Electrode Placement*Meditation interaction p = 0.001. The R TPJ*LKM groups show a significantly more positive shift in valence ratings (averaging over IAPS image type) compared to the other groups. Effects are curiously similar for sham and active current strengths.

$p = 0.001$, see Table 2 & Figure 4). Post-hoc testing of contrasts (see Table 3) indicated a significant effect of LKM versus control for the right TPJ site (averaging across current conditions) (LKM > Control mean difference = 0.30, $p < 0.001$, Cohen's d = 1.06) and no effect of LKM for the left dlPFC placement (LKM < Control mean difference = −0.11, $p = 0.230$, Cohen's d = −0.38). We also tested contrasts of electrode placements within the LKM and control conditions (Table 5). While there were no effects of electrode placement within control participants (Within Control: right TPJ < left dlPFC mean difference = −0.13, $p = 0.164$, Cohen's d = −0.45), among those receiving LKM, participants with an electrode over the right TPJ provided significantly more positive affect ratings compared to those with an electrode over the left dlPFC (Within LKM: right TPJ > left dlPFC mean diff. = 0.28, $p < 0.001$, Cohen's d = 0.98).

Results by image type indicated a significant interaction of image type*electrode placement*meditation ($F(3,83) = 3.234$; p = 0.017, see Table 4 & Figure 5) and image type*current*electrode placement ($F(3,83) = 2.659$; $p = 0.04$, see Table 4). Tests of pairwise contrasts within the image type*electrode placement*-meditation interaction (5 & Figure 5) show that for neutral and positive image types, participants practicing LKM with a right TPJ electrode reported more positive affect ratings. Contrasts of LKM vs. control on affect ratings, showed that participants in the right TPJ condition had more positive ratings for neutral (Within right TPJ: LKM > Control mean diff. = 0.33, $p = 0.002$, d = 0.96, see Table 5), low arousal/positive (Within right TPJ: LKM > Control mean diff. = 0.51, $p < 0.001$, d = 1.00, see Table 5), and high arousal/positive images (Within right TPJ: LKM > Control mean diff. = 0.36, p = 0.017, d = 0.74, see Table 5). This relationship was not present for low or high arousal/negative image types. There were also no significant differences between LKM and control groups within the left dlPFC placement (Figure 6).

Contrasts of electrode placements within levels of meditation group do show, however that for low arousal/positive image types only, participants in the left dlPFC condition and control condition (averaging over current) reported higher affect ratings than individuals in the right TPJ and control conditions (Within Control: right TPJ < left dlPFC mean diff. = −0.44, $p = 0.008$, d = −0.86, see Table 5). At every other level of image type, control participants did not report differences on affect ratings. For LKM participants however, those in the right TPJ condition reported significantly more positive affect ratings on neutral (Within LKM: right TPJ > left dlPFC mean diff. = 0.39, $p < 0.001$, d = 1.14, Table 5) and low arousal/positive image types (Within LKM: right TPJ > left dlPFC mean diff. = 0.38, $p = 0.014$, d = 0.75, Table 5).

Pairwise contrasts within the image type*current*-electrode placement interaction (Table 6) were not significant, however the means show sham right TPJ participants reported more positively on affect ratings of low arousal/negative images than sham dlPFC

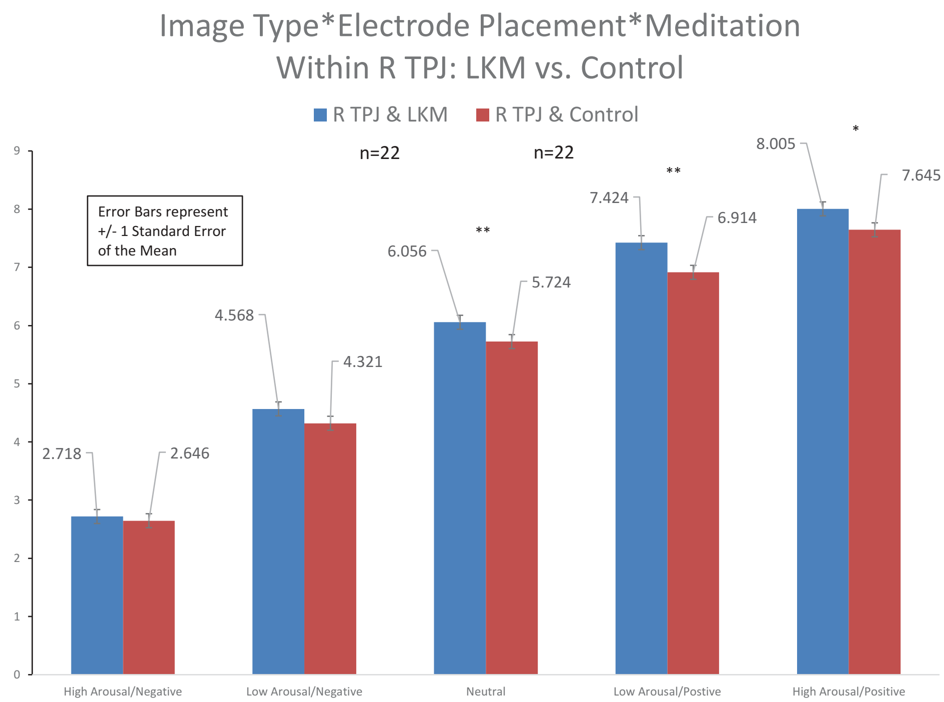

Figure 5.

Note: *Significant at p < 0.05; **Significant at p < 0.01; * * *Significant at p < 0.001. This figure shows differences between participants wearing R TPJ electrodes (averaging over current strength) who practiced LKM vs. listened to the control recording. R TPJ wearers who practiced LKM show significantly more positive valence ratings for neutral, low arousal/pos., and high arousal/pos. images while negative image types are rated similarly to control subjects.

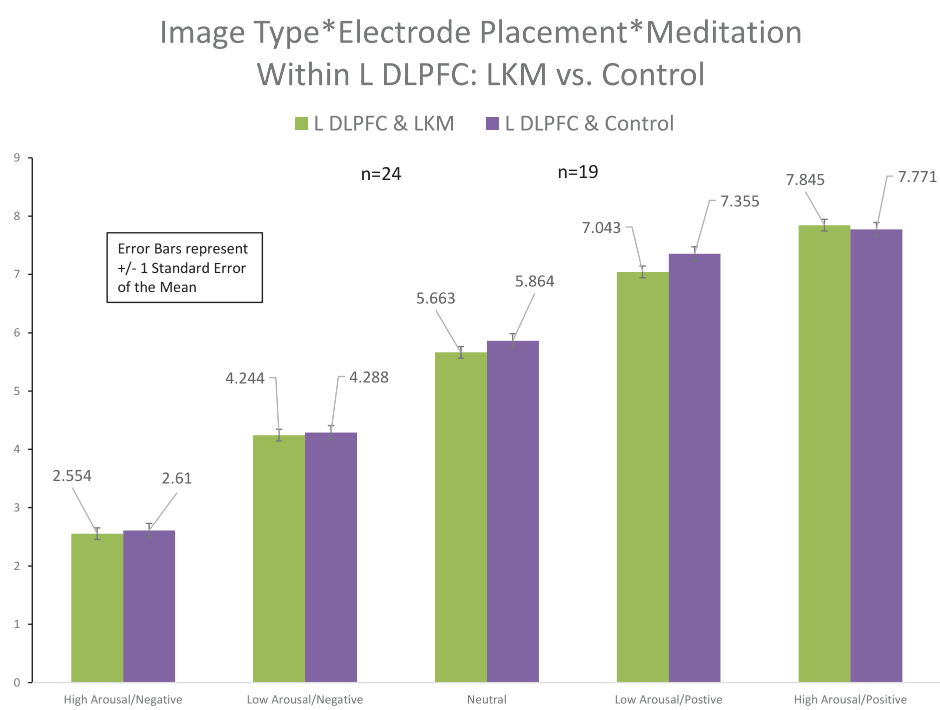

Figure 6.

Note: *Significant at p < 0.05; **Significant at p < 0.01; ***Significant at p < 0.001. This figure shows differences between L. DLPFC electrode-wearers who practiced LKM vs. listened to the control recording.

Table 7. MSCEIT total score results: main effects & interactions.

Variables	Groups (1 v 2)	M_1 (SE)	M_2 (SE)	F	p	d	N_1	N_2
Current	(2.0 v 0.1)	100.32 (1.75)	101.411 (1.98)	0.170	0.778	−0.1	40	34
Electrode Placement	(right TPJ v dlPFC)	102.04 (1.78)	99.69 (1.95)	0.796	0.408	0.21	39	35
Meditation	(LKM v Control)	100.29 (1.70)	101.44 (2.02)	0.191	0.371	−0.1	42	32
Current*Electrode Placement	All Groups	N/A	N/A	0.303	0.584	N/A	74	
Current*Meditation	All Groups	N/A	N/A	0.060	0.807	N/A	74	
Electrode Placement* Meditation	All Groups	N/A	N/A	0.641	0.426	N/A	74	
Current*Electrode Placement *Meditation	All Groups	N/A	N/A	0.085	0.772	N/A	74	

participants (Within Sham: right TPJ > left dlPFC mean diff. = 0.33, *p* = 0.055, d = 0.60, see Table 6). For neutral images, active right TPJ participants reported more positivity on affect ratings compared to active dlPFC participants (Within Active: right TPJ > left dlPFC mean diff. = 0.19, *p* = 0.083, d = 0.54, see Table 6).

Power analyses indicate that the image type*current*-meditation interaction which was marginal here (F = 2.197, p = 0.078, Table 4) might have reached significance if the overall sample size were increased to N = 104 (assuming 80% power to detect effects). This is meaningful in that the contrast of LKM – control shows a Cohen's d of 0.64 for active participants but a −0.24 for sham participants on affect ratings of low arousal/positive images. For high arousal/positive images, group differences between LKM and control show a Cohen's d of 0.72 (LKM vs. control) for participants assigned to active tDCS and Cohen's d of 0.17 (LKM vs. control) for participants assigned to sham tDCS.

MSCEIT results

Analysis of variance indicated no significant main or interaction effects of meditation, tDCS current strength, or electrode placement on the MSCEIT total scores (see Table 7) or sub-scale scores. The BFI dimension, Openness, correlated with MSCEIT Total (r = 0.38, *p* = 0.009) and the Experiential sub-dimension scores (r = 0.39, *p* = 0.007, see Table 8). Although there were no significant differences on EI, participants in the right TPJ and LKM conditions had the highest EI total scores (Figure 7). Importantly, well over half of the participants selected the same answers on 93 out of the 141 items on the MSCEIT and almost a tenth of the items show less than 0.1 variance. Therefore, the MSCEIT may not have been sensitive to group differences following the experimental manipulations.

Discussion

The results of the current study support the utility of loving kindness meditation (LKM) as a method for enhancing positive affect toward emotional images. While effects are present for those receiving stimulation at the right TPJ and not the left dlPFC, differences between 0.1mA and 2.0mA groups leave the role of stimulation inconclusive. Power analyses of the medium effect sizes obtained from the null results on current strength suggest these lack of findings could be a result of low sample size.

Additionally and contrary to our hypotheses, the current study did not find evidence of a brief (30 minute) LKM having an effect on EI, as measured by the MSCEIT. Despite these null effects, LKM practice does show evidence of resulting in positive shifts in affective experience for ambiguous and already-positive visual stimuli. This effect is not found for negative stimuli suggesting LKM confers a positive shift in affective experience while leaving sensitivity to negative content intact. These effects are robust, surviving sensitivity analyses with or without age, sex, ethnicity, BFI, and tDCS sensation covariates and exist only for participants in the right TPJ condition.

A positive shift in affect for neutral and positive images is an expected finding however a lack of positive shift for negative images is interesting in that others have found less-negative affective ratings after LKM training (Hutcherson et al., 2008; Klimecki et al., 2012). It may be the case that LKM changes shifts in affective mood while preserving the salience of negative stimuli. Additionally, because prior studies have not examined the impact of LKM on a range of evaluative valence, LKM has largely been assumed to induce a general, positive shift in affective experience. Hutcherson and colleagues (2008), found that after only 7 minutes of LKM practice, participants' affect ratings of neutral and positive stimuli (strangers and objects) became more positive than controls'. While our findings compliment Hutcherson's, they also demonstrate that LKM participants' perception of negative stimuli remains unaffected.

There are several potential explanations for why our study did not show an effect of LKM on the MSCEIT. First, we only administered the MSCEIT at post-test and it is unclear whether there might have been changes in EI that we could not detect because we did not include a pre-test. Second, it may be the case that the MSCEIT is

Table 8. Correlations for key study variables.

Variables	*M* (*SD*)	Current	Electrode Placement	Meditation	Sex	Age	B. Affect	P. Affect	MSCEIT Experiential	MSCEIT Reactive	MSCEIT Total	Extraversion	Conscientiousness	Neuroticism	Agree-ableness	Openness
Current (0 = Sham, 1 = Active)	0.51 (0.5)	1	−0.01 (p = 0.92)	0.08 (p = 0.46)	−0.06 (p = 0.59)	−0.02 (p = 0.89)	−0.08 (p = 0.44)	−0.07 (p = 0.52)	0.01 (p = 0.92)	−0.06 (p = 0.61)	−0.05 (p = 0.69)	0.03 (p = 0.80)	−0.06 (p = 0.67)	−0.04 (p = 0.76)	0.02 (p = 0.88)	0.08 (p = 0.57)
Electrode Placement (0 = dlPFC, 1 = right TPJ)	0.51 (0.5)		1	−0.06 −0.59	−0.06 (0.59)	−0.04 (0.72)	0.002 (0.99)	0.1 −0.37	0.08 −0.52	0.125 −0.29	0.124 −0.29	−0.048 −0.715	0.021 −0.873	0.053 −0.69	−0.021 −0.88	0.13 −0.32
Meditation (0 = Control, 1 = LKM)	0.53 (0.5)			1	0.02 (0.88)	−0.05 (0.67)	0.02	0.13	−0.04	−0.06	−0.06	0.02	−0.04	−0.05	0.05	0.1
Gender (0 = F, 1 = M)	0.28 (0.45)				1	0.04 −0.69	−0.85 **−0.22*** **-0.04**	−0.23 **−0.25*** **-0.02**	−0.74 −0.06 −0.62	−0.62 −0.19 −0.1	−0.64 −0.16 −0.17	−0.89 −0.11 −0.43	−0.76 0.01 −0.95	−0.72 −0.22 −0.09	−0.7 −0.24 −0.07	−0.47 −0.08 −0.56
Age	20.22 (4.0)				–	1	0.02 −0.88	−0.10 −0.35	0 −0.99	0.02 −0.88	0 −0.99	0.25 −0.06	0.1 −0.46	**−0.30*** **-0.02**	0.19 −0.15	0.04 −0.78
Baseline Affect Ratings	5.58 (0.53)						1	**0.86***** **(<0.001)**	−0.1 −0.42	−0.07 −0.53	−0.1 −0.42	−0.08 −0.55	−0.21 −0.11	−0.10 −0.44	−0.01 −0.97	−0.12 −0.36
Posttest Affect Ratings	5.60 (0.62)							1	−0.03 −0.83	0.06 −0.63	0.03 −0.8	−0.08 −0.55	−0.17 −0.2	−0.02 −0.91	−0.05 −0.68	−0.11 −0.42
MSCEIT Experiential	105.8 (12.0)								1	**0.37**** **-0.001**	**0.80***** **(<0.001)**	0.04 −0.78	−0.02 −0.9	−0.01 −0.94	−0.24 −0.11	**0.39**** **-0.007**
MSCEIT Reactive	95.45 (9.31)									1	**0.85***** **(<0.001)**	0.18 −0.23	0.06 −0.69	−0.16 −0.29	−0.18 −0.24	0.25 −0.1
MSCEIT Total	100.76 (10.67)										1	0.14 −0.34	0.04 −0.81	−0.09 −0.54	−0.23 −0.12	**0.38**** **-0.009**
Extraversion	25.64 (6.35)											1	0.19 −0.15	**−0.42**** **-0.001**	0.23 −0.08	**0.32*** **-0.01**
Conscientiousness	34.63 (4.37)												1	−0.02 −0.91	**0.36**** **-0.006**	0.2 −0.13
Neuroticism	22.32 (4.57)													1	−0.16 −0.22	−0.24 −0.07
Agreeableness	36.25 (4.38)														1	0.14 −0.28
Openness	37.15 (5.2)															1

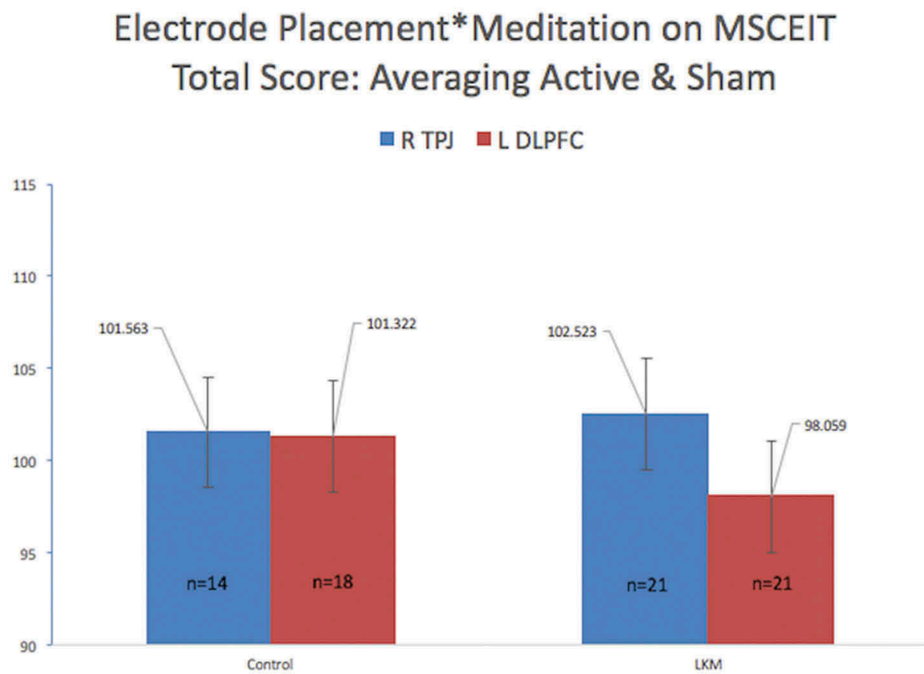

Figure 7.

Note: Error bars represent ± 1 standard error. This figure shows the difference in means on groups within the Electrode Placement*Meditation interaction on EI as mesasured by the MSCEIT. Although none of the results are significant, R TPJ*LKM participants are only a few (2–3) points away from showing significantly higher EI.

not sensitive to a brief training in LKM. Alternatively, descriptive statistics show that across all participants tested on this measure, the same answer choices were endorsed for well over half of the participants on over half of the items. Other findings have shown that the MSCEIT may only be sensitive to differences in EI for those who test low on the construct (Fiori et al., 2014) and others acknowledge room for improvement on the MSCEIT's construct validity (Maul, 2012). It is further possible that a larger sample may reveale group differences on the MSCEIT given that participants in right TPJ*LKM condition, who reported the most positive perception on IAPS affect ratings also scored highest on EI.

Given that there are no recorded findings or modeling simulations that we know of to support 0.1mA of current having an effect compared to the recommended 1.0–2.0mA protocols (Reinhart, Cosman, Fukuda, & Woodman, 2017; Woods et al., 2016), we cannot conclude any effect of current strength on LKM, despite the observed statistical interaction between TPJ stimulation site and LKM. A placebo effect of tDCS location is possible yet any such effects would still be isolated to the right TPJ and not left dlPFC, which makes this explanation implausible. The sensation data suggested no effects of electrode montage (right TPJ vs. left dlPFC) on experiences of sensations, so differences between sites on stimulation-related discomfort do not explain the findings. One possibility for the existence of results by placement may be that the F3 (left dlPFC) and CP6 (right TPJ) placements required different methods of head-wrapping to fix electrodes during meditation which may have resulted in electrode placement differences due to comfort that were not necessarily stimulation-related. The CP6 placement required at least one additional step to administer and typically consisted of a "headband" style of wrapping whereas the F3 placement more often required additional wrapping around the face and chin to remain affixed. All participants included in the study were right-handed leading to the possibility that simply wearing a right-lateralized electrode facilitated a state of comfort conducive to LKM whereas a left-lateralized electrode for right-handed participants may have been counter-productive to achieving LKM-related benefits.

Lack of effects due to current may also be due to the underpowered sample size. While it is possible that sham current produces neurostimulative effects, there is no existing body of literature that we know of to support that conclusion. Nevertheless, the efficacy of LKM for participants in the right TPJ condition and the strength of those effects provides modest evidence that LKM may enhance the affective experience of neutral or positive visual stimuli in favor of more positive evaluations. Individuals who received LKM with the right TPJ electrode also scored highest on EI, as measured by the MSCEIT, which is congruent with our hypothesized idea that LKM practice would coincide with greater EI. However, due to a lack of power and a possible ceiling effect on the MSCEIT, there are no significant differences between groups on EI.

Limitations and future directions

One of the major limitations of this work is the small sample size and number of experimental conditions, resulting in small cell sizes. Cell sizes of 30 or more may produce more reliable and interpretable results (Thiemann & Kraemer, 1987; VanVoorhis & Morgan, 2007). Cell sizes for the current study ranged from 19–24 and post-hoc power analyses indicated the study was underpowered to detect at least one hypothesized interaction effect (current*electrode placement*meditation). Additional limitations of the current study include the short duration of LKM training, the focus on individuals who were explicitly enrolling in the study to learn LKM (and therefore may have been more motivated than those without a strong interest in the practice), and the recruitment of a college student sample. Moreover, the MSCEIT shows signs of a ceiling effect in our sample and others have questioned its validity as a measure of EI (Maul, 2012). Ideally, future studies should make use of neuroimaging to study changes in neural circuitry after LKM and neurostimulation together using other measures of EI and more detailed measures of affective experience.

Conclusion

The present study was designed to enhance emotional intelligence (EI) and responses to emotional stimuli using loving kindness meditation (LKM) and transcranial direct current stimulation (tDCS). Our results indicate an effect of LKM driving positive affect ratings on neutral and positive IAPS stimuli without changing evaluations of negative stimuli. It is uncertain how tDCS compliments this effect or why LKM was only successful among individuals receiving some form of stimulation (sham or active) at the right temporoparietal junction but not the left dorsolateral prefrontal cortex. Additional research will be necessary to pinpoint the exact mechanistic contributions of stimulation to mindfulness meditation. Our results show affect ratings for negative content remain unaffected implying that LKM alters an individual's affective experiences of perceived neutral and positive valence without affecting sensitivity to negative valence. In the context of other studies showing increases of self-experienced positive affect with greater empathy and connectedness (Hutcherson et al., 2008; Klimecki et al., 2012; Kok & Singer, 2017; Mascaro et al., 2012), our results may indicate that LKM alters an individual's felt experience without harming sensitivity to the negative experiences of others.

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