Self-reported Outcome Expectations of Non-invasive Brain Stimulation Are Malleable: a Registered Report that Replicates and Extends Rabipour et al. (2017)

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Abbreviations
NIBS Non-invasive brain stimulation
EAS Expectation Assessment Scale
CES Cranial electrotherapy stimulation
tES Transcranial electric stimulation
SIMS Situational Motivation Scale
PSS Perceived Stress Scale
NFC Need for cognition
GMQ Growth Mindset Questionnaire
GSE General Self-Efficacy Scale
ARCES Attention-Related Cognitive Errors Scale
MASS-LO Mindful Attention Awareness Scale – Lapses Only

Introduction

Non-invasive brain stimulation (NIBS), which involves sending electrical stimulation through the scalp to target sub-cranial regions (Knotkova et al., 2019; Miniussi et al., 2013), is gaining popularity among scientists, practitioners, and vendors (Simons et al., 2016) as a method to achieve cognitive enhancement. NIBS as a cognitive enhancement method has been investigated in many different populations, ranging from the average healthy layperson (Brunyé et al., 2021; Fioel et al., 2008; Hill et al., 2016; Horvath et al., 2015a, 2015b; Mancuso et al., 2016) to military personnel (Brunyé et al., 2020) and clinical populations (Brunyé et al., 2021; Ciullo et al., 2021; Freitas et al., 2011; Hill et al., 2016; Suarez-Garcia et al., 2020). Using NIBS as a cognitive enhancement method is a tantalizing prospect because it is relatively inexpensive, largely safe, and easy to administer (Bikson et al., 2016).

However, findings on whether NIBS techniques enhance cognitive domains are mixed. Some studies have found NIBS to be an effective tool for cognitive enhancement (Au et al., 2016; Dockery et al., 2009; Katz et al., 2017; Morales-Quezada et al., 2015; Parasuraman & McKinley, 2014; Richmond et al., 2014; Southworth, 1999; Vodyanyk et al., 2021). Other studies have found detrimental effects (Brunyé et al., 2018; Pyke et al., 2020) or no reliable effects (Horne et al., 2020; Horvath et al., 2015a, 2015b; Mancuso et al., 2016; Medina & Cason, 2017; Nilsson et al., 2017; Rabipour et al. 2018b, 2019; Talsma et al., 2017; van Elk et al., 2020). These conflicting findings demonstrate how difficult it is to determine whether NIBS can reliably achieve cognitive enhancement.

A potential reason for these mixed results could be the failure to account for expectations of outcomes, which can skew participants’ perceptions of improvement from interventions and possibly lead to positive expectancy or placebo and placebo-like effects (Benedetti, 2014; Boot et al., 2013; Braga et al., 2021; Foroughi et al., 2016; Rabipour et al., 2018a; Rabipour et al., 2017, 2019; Rabipour et al., 2018b; Rabipour & Davidson, 2015; Schwarz et al., 2016; Simons et al., 2016), though this has not been observed in all cognitive enhancement studies (Denkinger et al., 2021; Tsai et al., 2018; Vodyanyk et al., 2021). Outcome expectations could partially or fully explain any cognitive enhancement gains of NIBS interventions. For instance, if participants partook in a study that explicitly stated the many benefits of NIBS for cognitive enhancement (e.g., in the consent form or other experimental materials) and are thus primed to believe that...
the intervention will be very effective, it is possible these participants may invest more time, energy, and resources into the NIBS intervention and associated outcome tasks than those who were not primed or were primed to have negative expectations about the intervention.

Recent research by Rabipour and colleagues (Rabipour & Davidson, 2015; Rabipour et al., 2017, 2018a, 2018b, 2019) has sought to understand better how expectations of outcomes relate to cognitive enhancement via NIBS. They have investigated NIBS outcome expectations by designing the Expectation Assessment Scale (EAS; Rabipour & Davidson, 2015; Rabipour et al., 2018a). The EAS is a questionnaire that asks respondents to provide success ratings, and confidence in those success ratings, for seven cognitive domains (e.g., memory) that could be impacted by NIBS cognitive enhancement methods (Rabipour & Davidson, 2015; Rabipour et al., 2018a). Researchers have administered the EAS with in-person, physically present samples (Rabipour et al., 2017, 2018b, 2019) and online, recruited entirely via the Internet samples (Rabipour & Davidson, 2015; Rabipour et al., 2017, 2018a), and the questionnaire has reliable psychometric properties in these particular samples (Rabipour et al., 2018a). When administering the EAS at baseline, individuals report feeling either neutral (Rabipour et al., 2019, 2018b) or somewhat optimistic (i.e., one rating above neutral; Rabipour & Davidson, 2015; Rabipour et al., 2017) toward NIBS for cognitive enhancement, and most people are typically confident in these responses (Rabipour et al., 2017).

Interestingly, participants’ expectations about NIBS for cognitive enhancement may be malleable. After a baseline administration of the EAS, Rabipour et al. (2017) used a within-subjects design to present participants with three sets of messages that primed different expectations about NIBS for cognitive enhancement. These messages set neutral expectations (e.g., “You are about to begin a brain stimulation program”), low or pessimistic expectations (e.g., “You are about to begin a brain stimulation program, designed based on unconfirmed theories about brain function”), and high or optimistic expectations (e.g., “You are about to begin a brain stimulation program designed by neuroscientists, based on work proven effective in scientific studies”) for using NIBS to achieve cognitive enhancement. Compared to baseline, there were significant decreases and increases in participants’ expectations of outcomes in the low and high expectation message conditions, respectively (Rabipour et al., 2017). This finding supports the possibility that the framing of recruitment materials, consent forms, and experimenter instructions could be playing a central role in the mixed results observed in NIBS cognitive enhancement studies.

The aim of the present study within this Registered Report was to understand for whom outcome expectations are most malleable. To achieve this aim, we conceptually replicated Rabipour et al.’s (2017) research with several changes. First, we used a between-subjects design for expectation primes, rather than a within-subjects design as Rabipour et al. (2017) did, to eliminate any possible carryover effects. Specifically, all participants completed the EAS at baseline, and then they completed it once again after being randomly assigned to read a neutral, low, or high expectation prime. We recruited a large enough sample to ensure sufficient statistical power for this design change as dictated by an a priori sample size estimate.

Further, we evaluated a refined version of the EAS. The original EAS included an item on “multitasking ability (i.e., managing multiple tasks at the same time)” (Rabipour & Davidson, 2015; Rabipour et al., 2018a). This definition implies dual-tasking ability, yet multitasking can also be conceptualized as task-switching ability or switching between multiple tasks (Koch et al., 2018; Ward et al., 2019). Task-switching and dual-tasking abilities are similar yet distinct manifestations of multitasking, and it is important to clarify the distinction between these processes because they have different theoretical implications (Koch et al., 2018; Ward et al., 2019). To account for this, we included an additional domain within the EAS to capture expectations surrounding task-switching ability. Rabipour et al. (2017) presented EAS items in a fixed order, leaving results open to potential order effects. To address this possibility in the current study, we presented EAS items in a different random order for each participant. In addition to individually evaluating each EAS item like Rabipour et al. (2017), we calculated a composite EAS by averaging all eight item areas to facilitate a more accessible interpretation of our results.

The present study also focused on cranial electrotherapy stimulation (CES), which involves administering alternating current with two bilateral electrodes typically attached to the earlobes or temples (Knotkova et al., 2019), rather than NIBS more broadly as Rabipour et al. (2017). We chose to focus on CES because participants are unlikely to hold preexisting expectations regarding CES effectiveness, unlike other methods like transcranial electric stimulation (tES) which is increasing in popularity, press coverage, and consumer productization. Our laboratory is also examining the physiological, neural, psychological, and behavioral influences of CES (Wooten et al., n.d.), and our research procedures will benefit from the outcomes of the current study.

In addition to conceptually replicating Rabipour et al. (2017), we also expanded upon their research in a novel way. We explored how individual differences across various self-reported psychological factors were related to the malleability of outcome expectations. Psychological factors have been explored within the context of cognitive training interventions (i.e., structured practice of cognitive tasks, typically digital), albeit with mixed results (Guye et al., 2017; Harrell
et al., 2019; Jaeggi et al., 2014; Minear et al., 2016; Örskov et al., 2021; Sprenger et al., 2013). Some of the previous studies that have investigated the effectiveness of NIBS for cognitive enhancement have primarily explored demographics (e.g., age) as an individual difference variable (Arciniega et al., 2018; Loor et al., 2016; Talsma et al., 2017), though some studies have found associations between motivation and outcomes (Jones et al., 2015; Katz et al., 2017; Rabipour et al., 2018b). We leveraged prior research on individual differences in psychological factors, primarily from cognitive training studies, to inform potential individual differences across psychological factors that might affect expectations of NIBS for cognitive enhancement.

We were specifically interested in exploring how situational motivation (i.e., intrinsic motivation, identified regulation, external regulation, amotivation), perceived stress, cognition-related beliefs (i.e., need for cognition, growth mindset, self-efficacy), and perceptions of real-world cognition (i.e., cognitive failures, attentional lapses) related to NIBS outcome expectations. An individual’s motivation for (Boot et al., 2013; Jones et al., 2015; Katz et al., 2017; Rabipour et al., 2018b; Simons et al., 2016) and stress toward (Minear et al., 2016; Örskov et al., 2021) pursuing cognitive enhancement could influence their expectations about NIBS success rates. Regarding cognition-related beliefs, and in particular growth mindset, those who believe their cognitive abilities are fixed may not expect NIBS to be successful for cognitive enhancement or vice versa (Foroughi et al., 2016; Guye et al., 2017; Jaeggi et al., 2014). Similarly, if someone perceives that they commit many cognitive failures and that their cognitive abilities could be improved (or not), they may have higher (or lower) expectations for cognitive enhancement (Harrell et al., 2019; Jaeggi et al., 2014). Investigating if and how various psychological factors are related to NIBS outcome expectations can help identify if certain characteristics are more or less likely to make a person responsive to cognitive enhancement.

To address our aims, we pre-registered our analysis plans in our Stage 1 manuscript (https://osf.io/pysnu/) which received in principle acceptance from the Journal of Cognitive Enhancement on 6 September 2021, prior to data collection. Any deviations from our approved report are explicitly noted when applicable. For our first analysis, we tested for baseline differences among the expectation prime groups across select demographics, expectation success and confidence ratings, and all psychological constructs. This baseline analysis allowed us to confidently infer if our obtained results could be attributed to our manipulation and not preexisting group differences. Second, we sought to understand how different expectation primes could affect participants’ expectations of NIBS cognitive enhancement outcomes over time. We predicted that compared to baseline EAS success ratings, those who read the low and high expectation primes would have decreased and increased success ratings on all EAS item areas and the composite EAS, respectively. We did not anticipate any differences between baseline EAS success ratings and post-prime EAS success ratings among the neutral expectation prime group. This predicted pattern of results would replicate findings from Rabipour et al. (2017). Finally, we wanted to further tease apart the aforementioned analysis and investigate if the interaction between expectation prime and time changed when also considering situational motivation (i.e., intrinsic motivation, identified regulation, external regulation, amotivation), perceived stress, cognition-related beliefs (i.e., need for cognition, growth mindset, self-efficacy), and perceptions of real-world cognition (i.e., cognitive failures, attentional lapses). We did not pre-register any predictions about directionality or selectivity of effects for these additional exploratory analyses. However, we reasoned that any significant covariates or expectation prime interactions with covariates would signal a potential relationship between the individual difference variable and responses to expectation primes.

**Method**

**Participants**

We based our sample size on an a priori power analysis using the R package “pwr2” (version 1.0; Lu et al., 2017). We assumed a small effect size ($f = 0.1$) with three groups (expectation prime: neutral, low, high), two within-subjects timepoints (baseline/pre-prime, post-prime), alpha ($\alpha \leq 0.05$), and power = 0.90. This resulted in 101 participants per group. Given this was one of the first investigations of expectations malleability for NIBS using a mixed analysis of variance (ANOVA) design, we proposed doubling our calculation to 202 participants per group. We also aimed to recruit an additional 20 participants for each group to account for attrition and data loss. Thus, our target sample size was 666 participants.

All participants were recruited through Prolific. Prolific is an online data collection platform tailored to social and behavioral researchers that offers high-quality data with a diverse and na"ive population (Palan & Schitter, 2018; Peer et al., 2014). To have been eligible to participate in our study, Prolific workers must have been 18 years or older, living in the USA, and had a 95% or higher approval rating on Prolific. We planned to reject submissions from those who completed the study exceptionally fast, which we defined as three median absolute deviations (MADs) below the median completion time. MADs are less sensitive to outliers than means and standard deviations (Leys et al., 2013). However, no submissions met this criterion.
We rejected submissions from two Prolific workers who failed two attention checks that were two separate items disguised within separate surveys and directed for a specific answer (e.g., “Please mark ‘Rarely’ for this question”; Hauser & Schwarz, 2016).

We recruited a sample of 667 participants and randomly assigned them to the neutral, low, or high expectation prime condition. Per our pre-registration, we excluded 12 participants from data analysis who indicated that they randomly responded during some point of the study (Penneycook et al., 2017; Ralph & Smilek, 2017), which left a total of 655 participants ($n=216$ neutral expectation prime; $n=219$ low expectation prime; $n=220$ high expectation prime), meeting our intent to double the a priori sample size estimate. On average, participants were 30.12 years old ($SD=10.45$ years; median = 27 years; minimum = 18 years; maximum = 82 years) (see Table 1 for information on categorical demographics).

For comparison, Rabipour et al. (2017) reported analyzing data from 428 participants that were classified as younger adults ($n=300$; age $M=23.19$ years, age $SD=5.39$ years; 190 women; education $M=14.11$ years, education $SD=4.72$ years), middle-aged adults ($n=50$; age $M=45.28$ years, age $SD=6.70$ years; 31 women; education $M=15.10$ years, education $SD=2.48$ years), or older adults ($n=78$; age $M=66.58$ years, age $SD=5.34$ years; 51 women; education $M=14.64$ years, education $SD=2.50$ years). The weighted average age across Rabipour et al.’s (2017) sample was 33.68 years old (weighted $SD=17.03$ years), with 40% ($n=172$) of the sample identifying as women. The weighted average education was 14.32 years (weighted $SD=0.35$ years). When comparing our results to Rabipour et al. (2017), we focused primarily

### Table 1

| Demographic                                      | Count | % of total |
|--------------------------------------------------|-------|------------|
| Gender                                           |       |            |
| Man                                              | 151   | 23%        |
| Woman                                            | 485   | 74%        |
| Non-binary                                       | 15    | 2%         |
| Prefer to self-describe                          | 2     | <1%        |
| Prefer not to answer                             | 2     | <1%        |
| Ethnicity                                        |       |            |
| Of Hispanic, Latino, or Spanish origin            | 70    | 11%        |
| Not of Hispanic, Latino, or Spanish origin        | 583   | 89%        |
| Prefer not to answer                             | 2     | <1%        |
| Race                                             |       |            |
| American Indian or Alaska Native                 | 6     | 1%         |
| Asian                                            | 22    | 3%         |
| Black, Afro-Caribbean, or African American        | 47    | 7%         |
| Native Hawaiian or Pacific Islander               | 1     | <1%        |
| White                                            | 531   | 81%        |
| Multi-racial                                     | 32    | 5%         |
| Prefer to self-describe                          | 10    | 2%         |
| Prefer not to answer                             | 6     | 1%         |
| Education                                        |       |            |
| Less than a high school diploma                  | 3     | <1%        |
| High school degree or equivalent (e.g., GED)      | 76    | 12%        |
| Some college and no degree                       | 172   | 26%        |
| Associate degree (e.g., AA, AS)                  | 53    | 8%         |
| Bachelor’s degree (e.g., BA, BS)                 | 256   | 39%        |
| Master’s degree (e.g., MA, MS)                   | 70    | 11%        |
| Professional degree (e.g., MD, DVM)              | 13    | 2%         |
| Doctorate (e.g., PhD, EdD)                       | 10    | 2%         |
| Prefer not to answer                             | 2     | <1%        |
| Online game familiarity/experience                |       |            |
| Yes                                              | 334   | 51%        |
| No                                               | 321   | 49%        |
| Brain stimulation familiarity/experience          |       |            |
| Yes                                              | 85    | 13%        |
| No                                               | 570   | 87%        |

Items were presented as single-answer, multiple-choice questions. Participants provided text responses if they selected the answer “Prefer to self-describe.” Values derived from the R package “jmv” (version 2.3.4; Selker et al., 2021).
on their young adult subsample because this subsample was closest in age to our sample.

Measures

Expectations of Outcomes

A modified version of the EAS (Rabipour & Davidson, 2015; Rabipour et al., 2018a) was used to measure the expected success of CES cognitive enhancement interventions. The original EAS includes seven items representing seven cognitive domains: (i) “general cognitive function,” (ii) “memory,” (iii) “concentration,” (iv) “distractibility (i.e., lowering how much you lose focus on a task),” (v) “reasoning ability,” (vi) “multitasking ability (i.e., managing multiple tasks at the same time),” and (vii) “performance in everyday activities (e.g., driving, remembering important dates, managing finances, etc.)”. For our purposes, we revised the EAS to include an additional cognitive domain: “task-switching ability (i.e., switch from performing one task to performing another task)”. Participants were asked how successful they would expect NIBS to be at improving the eight respective cognitive domains with the following 7-point Likert scale:

1 = Completely unsuccessful: No change in brain activity or noticeable behavior. Such a procedure would be a waste of time and resources.
2 = Fairly unsuccessful: Possible changes in specific brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life. Such a procedure would be a waste of time and resources.
3 = Somewhat unsuccessful: Possible changes in general brain activity (i.e., detectable at the neurological level), yet unnoticeable in daily life.
4 = I have absolutely no expectations.
5 = Somewhat successful: Possible changes in specific brain activity and behavior. Such a procedure would NOT be a waste of time or resources.
6 = Fairly successful: Possible changes in general brain activity as well as noticeable behavioral changes.
7 = Completely successful: Changes in general brain activity as well as noticeable changes in overall thought and behavior that positively impact daily life. Such a procedure would be a good investment of time and resources.

Participants also indicated if they were confident in their success rating with a yes/no response. Rabipour et al. (2017) individually evaluated each item, where a higher rating indicates a greater expectation of NIBS to successfully enhance the specific cognitive domain. In addition to analyzing the individual items, we calculated a composite EAS by averaging all eight areas. Cronbach’s alphas were α = 0.91 and α = 0.94 for baseline EAS success ratings and baseline EAS confidence ratings, respectively.

Situational Motivation: Intrinsic Motivation, Identified Regulation, External Regulation, Amotivation

The 16-item Situational Motivation Scale (SIMS; Guay et al., 2000) was used to assess anticipated situational motivation for engaging in CES for cognitive enhancement. The SIMS assesses four constructs: intrinsic motivation, identified regulation, external regulation, and amotivation. Each construct consists of 4 items. Example items from each respective construct include the following: “I would like to engage in CES because… I think that this activity would be interesting,” “I would like to engage in CES because… I think that this activity would be good for me,” “I would like to engage in CES because… I would feel like I have to do it,” and “I would like to engage in CES because… I don’t know; I don’t see what this activity would bring me”. Responses were given on a 7-point Likert scale (1 = “Corresponds not at all,” 2 = “Corresponds very little,” 3 = “Corresponds a little,” 4 = “Corresponds moderately,” 5 = “Corresponds enough,” 6 = “Corresponds a lot,” 7 = “Corresponds exactly”). Scores for each subscale were calculated by averaging together item responses.1 A higher score on each respective subscale indicates higher intrinsic motivation, identified regulation, external regulation, and amotivation for engaging in CES for cognitive enhancement. Cronbach’s alphas for the four subscales were: intrinsic motivation subscale α = 0.89, identified regulation subscale α = 0.92, external regulation subscale α = 0.87, and amotivation subscale α = 0.68.

Perceived Stress

The Perceived Stress Scale (PSS; Cohen et al., 1983) is a 10-item survey that measures an individual’s perceptions of stress over the past month that has ultimately caused life to feel unpredictable, uncontrollable, and overloaded. Example items include “In the last month, how often have you been upset because of something that happened unexpectedly?” and “In the last month, how often have you felt confident about your ability to handle your personal problems?”. Responses were given with a 5-point Likert scale (0 = “Never,” 1 = “Almost never,” 2 = “Sometimes,” 3 = “Fairly often,” 4 = “Very often”). Scores were calculated by summing all item responses and could range from 0 to 40.

1 In our Stage 1 Registered Report, we anticipated using a summary or composite score for the SIMS. After further reading, we opted to use the four-subscale approach that is most common in the broader SIMS literature (for more information, see Guay et al., 2000).
A higher score indicates greater stress. Cronbach’s alpha for the PSS was $\alpha = 0.90$.

**Cognition-related Beliefs**

**Need for cognition** The Need for Cognition (NFC; Cacioppo & Petty, 1982; Cacioppo et al., 1984) is an 18-item questionnaire that assesses how much an individual enjoys cognitively effortful tasks. Example items include statements such as “I would prefer complex to simple problems” and “I really enjoy a task that involves coming up with new solutions to problems”. Responses were given with a 5-point Likert scale (1 = “Extremely uncharacteristic,” 2 = “Somewhat uncharacteristic,” 3 = “Uncertain,” 4 = “Somewhat characteristic,” 5 = “Extremely characteristic”). Scores were calculated by summing all item responses and could range from 18 to 90. A higher score indicates a higher need for cognition. Cronbach’s alpha for the NFC was $\alpha = 0.93$.

**Growth mindset** The Growth Mindset Questionnaire (GMQ; Dweck, 2006) is a 20-item measure that assesses how likely an individual is to believe that certain mental abilities are fixed versus flexible. Example items include “All humans are capable of learning” and “Intelligence is something people are born with that can’t be changed”. Responses were given on a 4-point Likert scale (1 = “Strongly agree,” 2 = “Agree,” 3 = “Disagree,” 4 = “Strongly disagree”). Scores were calculated by summing all item responses and could range from 20 to 80. A higher score indicates a growth, rather than fixed, mindset where intelligence is viewed as a malleable, changeable construct. Cronbach’s alpha for the GMQ was $\alpha = 0.83$.

**Self-efficacy** The General Self-Efficacy Scale (GSE; Schwarzer & Jerusalem, 1995) is a 10-item questionnaire that assesses a general sense of self-efficacy. Example items include “I can always manage to solve difficult problems if I try hard enough” and “I can solve most problems if I invest the necessary effort”. Responses were given on a 4-point Likert scale (1 = “Not true at all,” 2 = “Hardly true,” 3 = “Moderately true,” 4 = “Exactly true”). Scores were calculated by summing all item responses and could range from 10 to 40. A higher score indicates a greater degree of self-efficacy, specifically as it pertains to coping with daily obstacles and adapting to stressful life events. Cronbach’s alpha for the GSE was $\alpha = 0.89$.

**Perceptions of Real-world Cognition**

**Cognitive failures** The Attention-Related Cognitive Errors Scale (ARCES; Carriere et al., 2008; Cheyne et al., 2006) is a 12-item questionnaire that measures how frequently individuals make minor mistakes because of absent-mindedness. Previous work has shown that scores on the ARCES are correlated with overall performance on the Sustained Attention to Response Task (SART), which is a cognitive behavioral task measure of sustained attention (Smilie et al., 2010). Some items from the ARCES are “I make mistakes because I am doing one thing and thinking about another” and “I have absent-mindedly placed things in unintentional locations”. Responses were collected using a 5-point Likert-type scale (1 = “Never,” 2 = “Rarely,” 3 = “Sometimes,” 4 = “Often,” 5 = “Always”). To easily interpret the ARCES alongside the other surveys, we reverse scored all items (1 = “Always,” 2 = “Often,” 3 = “Sometimes,” 4 = “Rarely,” 5 = “Never”). Survey scores were calculated by summing all item responses and could range from 12 to 60. With our scoring method, a higher score reflected a lower frequency of cognitive failures because of absent-mindedness. Cronbach’s alpha for the ARCES was $\alpha = 0.90$.

**Attentional lapses** The Mindful Attention Awareness Scale – Lapses Only (MAAS-LO; Carriere et al., 2008) is a 12-item survey derived from the 15-item Mindful Attention Awareness Scale (MAAS) developed by Brown and Ryan (2003). The MAAS-LO assesses the frequency with which individuals experience attentional lapses in everyday situations. Previous work has shown that scores on the MAAS-LO are correlated with overall performance on the SART (Smilie et al., 2010). The MAAS-LO includes items such as “I find myself doing things without paying attention” and “I find it difficult to stay focused on what’s happening in the present”. Responses were collected using a 6-point Likert-type scale (1 = “Almost never,” 2 = “Very rarely,” 3 = “Rarely,” 4 = “Occasionally,” 5 = “Frequently,” 6 = “Almost always”). To easily interpret the MAAS-LO alongside the other surveys, we reverse scored all items (1 = “Almost always,” 2 = “Frequently,” 3 = “Occasionally,” 4 = “Rarely,” 5 = “Very rarely,” 6 = “Almost never”). Survey scores were calculated by summing all item responses and could range from 12 to 72. With our scoring method, a higher score on the MAAS-LO represented a lower frequency of attention lapses. Cronbach’s alpha for the MAAS-LO was $\alpha = 0.91$.

**Procedure**

This study was approved by the Tufts University Institutional Review Board (#1908026). Prolific workers who met our screening criteria saw our study posting on the Prolific dashboard. If they decided to participate, they were re-directed to a Qualtrics survey. They first completed a captcha to confirm they were not a bot. If participants correctly completed this captcha, they were directed to the next page and provided informed consent. After answering demographic questions, all participants read
a baseline expectations message (see Fig. 1a) and completed a baseline administration of the EAS. Then, participants were randomly assigned to one of three expectation primes that set neutral (see Fig. 1b), low (see Fig. 1c), or high (see Fig. 1d) expectations for CES as a method for cognitive enhancement before completing the EAS once again. After, participants completed the SIMS because it is state-sensitive, and then completed the PSS, NFC, GMQ, GSE, ARCES, and MAAS-LO in a randomized order. When participants completed all questionnaires, they were asked if they randomly responded at any point during the study. Finally, participants were thanked, debriefed, and re-directed to the study posting on the Prolific dashboard and compensated at a rate of $10/h.

Results

In both manuscripts, we report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study. All data processing and analysis was conducted with R (version 4.1.3; R Core Team,
How successful do you expect non-invasive brain stimulation to be at improving...

(c) Low expectation prime:
Cranial electrotherapy stimulation (CES) is one type of non-invasive brain stimulation that delivers a small, pulsed, alternating current via small electrodes on the ears or the head.

Assume you are participating in a non-invasive brain stimulation program using CES, designed based on unconfirmed theories about brain function.

Controversial theories state that brain stimulation might improve mental health and cognitive functioning. Companies and other unscientific sources exploit these theories by claiming that, just like stimulating your body with exercise, stimulating your brain can help you feel better. These claims are not proven scientifically.

No program has been shown to prevent or even slow down the death of neurons resulting from age, injury, or disease. This process is believed to cause mental decline. No real change can result from brain stimulation, academics argue, and even the perception of improvement would not last.

Below are examples of points made in scientific articles that criticize brain stimulation (citations provided for your reference):

A recent systematic review of CES stimulation for neuromodulation in healthy and clinical samples found “limitations make it difficult to derive consistent or compelling insights from the extant literature, tempering our enthusiasm for CES and its potential to alter brain function, behavior, or endocrine responses reliably or robustly, in clinical or non-clinical settings” (Brunyé et al., 2021).

“[The U.S. Food and Drug Administration] has consistently stated that the effectiveness of CES has not been established by adequate scientific evidence” (Guleyupoglu et al., 2014).

“Available evidence regarding brain stimulation remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from brain stimulation” (Bahar-Fuchs et al., 2013).

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving...

(d) High expectation prime:
Cranial electrotherapy stimulation (CES) is one type of non-invasive brain stimulation that delivers a small, pulsed, alternating current via small electrodes on the ears or the head.

Assume you are participating in a non-invasive brain stimulation program using CES, designed by neuroscientists, based on work proven effective in scientific studies.

2022 in RStudio (version 2022.02.1; RStudio Team, 2022). Data were imported and exported using the “rio” package (version 0.5.29; Chan et al., 2021). Data were processed and manipulated with a collection of “tidyverse” (version 1.3.1.; Wickham et al., 2019) packages: “dplyr” (version 1.0.8; Wickham et al., 2021) and “tidyr” (version 1.2.0; Wickham, 2021). Data were analyzed using the “jmv” package (version 2.3.4; Selker et al., 2021). The box plot data visualization was created using “ggplot2” (version 3.3.5; Wickham, 2016), “ggthemes” (version 4.2.4; Arnold, 2021), and a “wesanderson” (version 0.3.6; Ram & Wickham, 2018) color palette. Data processing (https://osf.io/9ab6w/) and analysis (https://osf.io/y5pwr/) code are available on OSF.

We examined multiple levels of analysis and corrected our alpha thresholds accordingly, which we specified in our Stage 1 manuscript. At the primary level, we first determined whether to reject the null hypothesis for each ANOVA. Because the likelihood of incorrectly rejecting the null hypothesis increases with each ANOVA, we rejected the null hypothesis for each ANOVA model if the p-value was less than 0.05 divided by the number of ANOVAs we were running. At the secondary level, for any of the ANOVAs that were statistically significant based on the
adjusted alpha threshold, we examined the post hoc t-tests to better understand what is influencing the overall effects we detected at the primary ANOVA level. At this secondary level, we corrected for multiple comparisons using the Tukey HSD method with an alpha threshold of 0.05. We used the Tukey HSD method because we did not have a set number of planned comparisons, did not only make pairwise comparisons, and sample sizes were relatively equal among groups.

**Pre-registered Analyses**

**Baseline Differences Among the Expectation Prime Groups**

We tested for baseline differences among the three expectation prime groups for age, gender, the eight baseline EAS success ratings as well as their eight accompanying confidence ratings, and the 10 psychological factors of interest. The purpose of testing for any baseline differences among these variables was to ensure that our obtained results could be attributed to our manipulation versus preexisting group differences. Our first baseline analysis involved 20 univariate ANOVAs assuming equal variances. The predictor variable was the expectation prime (neutral, low, high). The outcome variables were age, gender, baseline EAS success ratings for the eight item areas (i.e., general cognitive function, memory, concentration, distractibility, reasoning ability, multitasking/dual-tasking ability, task-switching ability, performance in everyday activities), and scores for the 10 psychological factors (i.e., four SIMS subscales for intrinsic motivation, identified regulation, external regulation, and amotivation; PSS for perceived stress; NFC for need for cognition; GMQ for growth mindset; GSE for self-efficacy; ARCES for cognitive failures; and MAAS-LO for attentional lapses).

In our Stage 1 Registered Report, we originally proposed 17 univariate ANOVAS, and this was because we planned on using a single composite score for the SIMS (Guay et al., 2000). However, we later discovered that it is more common to separately examine the four sub-scale scores (Guay et al., 2000). For this reason, the number of univariate ANOVAs increased from 17 to 20. Because we were conducting many ANOVAs, we protected from Type I errors across the 20 models using a corrected alpha threshold of 0.003 (α = 0.05/20 ANOVAs) for our baseline analysis. If there were any baseline differences across groups, we pre-registered that we would control for any of these differentiating factors by including them as covariates in our primary analysis.

Table 2 displays results from the 20 univariate ANOVAs. To summarize, baseline success ratings for each EAS item were relatively and equally neutral (i.e., ratings

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**Research shows that this program can improve mental functions such as attention. This is similar to the way physical exercise improves muscle tone and performance. Just like stimulating your body with exercise, stimulating your brain can help you feel better.**

Converging evidence from various neuroimaging studies suggests CES reaches cortical and subcortical areas of the brain during application. Further, CES treatments have been found to induce changes in neurohormones and neurotransmitters that have been implicated in mood and well-being: substantial increases in beta endorphins, adrenocorticotrophic hormone, and serotonin.

Below are examples of points made in scientific articles that support brain stimulation (citations provided for your reference):

“Results showed improvements in the residents’ working memory, planning and organizing, task monitoring and ability to initiate. As noted above, changes in the subjects came after only five treatment sessions, which demonstrated the ability of CES to produce rapid, positive improvement in the subjects emotional and cognitive lives” (Mellen et al., 2016).

“The present study gives strong support for the clinical use of CES in treating stress-related cognitive dysfunction as defined herein, in both adults and children” (Smith, 1999).

“This study examined the effects of CES on various EEGs reflecting brain activities. These results suggest that the 0.5 Hz CES has a positive influence on brain activity for external information processing such as cognitive activity, while the 100 Hz CES has a positive influence on thinking activity accompanying mental load” (Lee et al., 2019).

After reading this message, how successful do you expect non-invasive brain stimulation to be at improving...
around 4) across the three conditions. Our findings replicated previous findings from Rabipour et al.’s (2017) subsample of young adults who reported that they had relatively neutral expectations (i.e., ratings around 4) for NIBS to achieve cognitive enhancement across EAS items.

According to our corrected alpha threshold of 0.003, expectation prime groups differed on two of the four situational motivation subscales: identified regulation ($F_{2,652} = 39.435, p < 0.001$) and amotivation ($F_{2,652} = 28.725, p < 0.001$). Identified regulation and amotivation were not highly correlated ($r = -0.343$). To determine where these differences existed, we examined post hoc comparison tests. For univariate ANOVAs, the “jmv” package (version 2.3.4; Selker et al., 2021) applies either Games-Howell or Tukey HSD post hoc corrections. We opted to apply Tukey HSD post hoc corrections. Participants in the high expectation prime group ($M = 4.523, SD = 1.627$) reported greater feelings of identified regulation compared to the neutral ($M = 3.712, SD = 1.579$) and low ($M = 3.183, SD = 1.572$) expectation prime groups ($ps < 0.001$). There was also a statistically significant difference in identified regulation between the neutral expectation prime group and the low expectation prime group ($p = 0.002$). Participants in the high expectation prime group ($M = 2.645, SD = 1.149$) reported significantly lower feelings of amotivation compared to the neutral ($M = 3.410, SD = 1.280$) and low ($M = 3.428, SD = 1.270$) expectation prime groups ($ps < 0.001$). There were additional post hoc differences for variables that were not statistically significant at the model level, and for conciseness, we are not reporting these values in our manuscript. Instead, we encourage readers to examine these values at https://osf.io/y5pwr/.

Like Rabipour and collaborators (2017), we also calculated eight $\chi^2$ tests of association to assess any differences in confidence ratings on each baseline EAS item across the three expectation prime groups. To reiterate, participants reported that they were either confident or not confident in their success ratings of each EAS item. To protect from type I errors, we used a corrected alpha threshold of 0.006 ($\alpha = 0.05/20 \chi^2$ tests) for the eight tests. For all tests, $df = 2$ and $N = 655$. Our expectation prime groups did not differ on baseline item confidence ratings for everyday cognitive function ($\chi^2 = 0.401, p = 0.818$), memory ($\chi^2 = 0.078, p = 0.962$), concentration ($\chi^2 = 2.320, p = 0.313$), distractibility ($\chi^2 = 0.149, p = 0.928$), reasoning ability ($\chi^2 = 0.061, p = 0.970$), multitasking (i.e., dual-tasking) ability ($\chi^2 = 3.365, p = 0.186$), task-switching ability ($\chi^2 = 0.29, p = 0.865$), and performance in everyday activities ($\chi^2 = 0.976, p = 0.614$). On average, across all baseline confidence item ratings regardless of expectation prime group, between 59 to 64% of participants reported feeling confident in their responses. It is worth noting that the frequency of baseline confidence ratings observed in our sample was lower than observed in Rabipour et al.’s (2017) young adult subsample, who reported that $\geq 74\%$ of participants ($\geq 222$ out of 300 participants) felt confident in their baseline EAS success ratings.

### Effects of Time and Expectation Prime on EAS

To understand how priming different expectations affected perceptions of CES cognitive enhancement success over time, we performed nine 2 (time: baseline/pre-prime, post-prime) × 3 (expectation prime: neutral, low, high) mixed ANOVAs. We included identified regulation and amotivation as covariates because of the baseline differences across the expectation prime groups. We first conducted this analysis with composite EAS as the outcome variable. Like Rabipour et al. (2017), we also performed this analysis for each of the eight areas assessed by the EAS. The “jmv” package (version 2.3.4; Selker et al., 2021) uses type III sums of squares. Because we were conducting many ANOVAs, we used a corrected alpha threshold of 0.006 ($\alpha = 0.05/9$ ANOVAs) to protect from type I errors across the models.

| Table 2 Baseline differences among expectation prime groups across select 20 variables | $F$ | df1 | df2 | $p$ |
|---|---|---|---|---|
| Age | 1.461 | 2 | 652 | 0.233 |
| Gender | 0.534 | 2 | 652 | 0.587 |
| Baseline EAS | | | | |
| Everyday cognitive function | 0.897 | 2 | 652 | 0.408 |
| Memory | 1.865 | 2 | 652 | 0.156 |
| Concentration | 1.825 | 2 | 652 | 0.162 |
| Distractibility | 2.689 | 2 | 652 | 0.069 |
| Reasoning ability | 0.076 | 2 | 652 | 0.927 |
| Multitasking (i.e., dual-tasking) ability | 0.026 | 2 | 652 | 0.947 |
| Task-switching ability | 0.500 | 2 | 652 | 0.607 |
| Performance in everyday activities | 0.015 | 2 | 652 | 0.985 |
| Situational motivation | | | | |
| Intrinsic motivation | 3.934 | 2 | 652 | 0.020 |
| Identified regulation | 39.435 | 2 | 652 | <0.001* |
| External regulation | 5.242 | 2 | 652 | 0.006 |
| Amotivation | 28.725 | 2 | 652 | <0.001* |
| Perceived stress | 2.088 | 2 | 652 | 0.125 |
| Need for cognition | 0.077 | 2 | 652 | 0.926 |
| Growth mindset | 0.165 | 2 | 652 | 0.848 |
| Self-efficacy | 2.228 | 2 | 652 | 0.109 |
| Cognitive failures | 0.598 | 2 | 652 | 0.550 |
| Attentional lapses | 3.907 | 2 | 652 | 0.021 |

The results from 20 univariate ANOVAs. Asterisks denote statistical significance at a corrected alpha threshold of 0.003 ($\alpha = 0.05/20$ ANOVAs). Data were analyzed with the R package “jmv” (version 2.3.4; Selker et al., 2021). EAS, Expectations Assessment Scale.
Table 3 Repeated measures ANOVA examining the effect of expectation prime on composite EAS over time

| Effect                                | SS     | df  | MS      | F      | p         | η²     |
|---------------------------------------|--------|-----|---------|--------|-----------|--------|
| **Within-subjects effects**           |        |     |         |        |           |        |
| Time                                  | 8.106  | 1   | 8.106   | 14.385 | <0.001    | 0.002  |
| Time × expectation prime              | 206.641| 2   | 103.320 | 183.360| <0.001    | 0.046  |
| Time × identified regulation          | 11.592 | 1   | 11.592  | 20.571 | <0.001    | 0.003  |
| Time × amotivation                    | 0.328  | 1   | 0.328   | 0.583  | 0.446     | <0.001 |
| Residual                              | 366.264| 650 | 0.563   |        |           |        |
| **Between-subjects effects**          |        |     |         |        |           |        |
| Expectation prime                     | 92.788 | 2   | 46.394  | 25.487 | <0.001    | 0.021  |
| Identified regulation                 | 284.470| 1   | 248.470 | 136.498| <0.001    | 0.055  |
| Amotivation                           | 5.369  | 1   | 5.369   | 2.950  | 0.086     | 0.001  |
| Residual                              | 1183.207| 650 | 1.820   |        |           |        |

Our corrected alpha rate was 0.006 (α=0.05/9 ANOVAs). Identified regulation and motivation were covariates. Data was analyzed with R package “jmv” (version 2.3.4; Selker et al., 2021). EAS, Expectations Assessment Scale; SS, type III sums of squares; MS, mean square

Fig. 2 Within-subjects effects of composite EAS by time and expectation prime. On the y-axis, a rating of 1 indicates lower expectations for NIBS as a cognitive enhancement method and a rating of 7 indicates higher expectations for NIBS as a cognitive enhancement method. Within the boxes, the horizontal lines represent the median of the data, and the black dots represent the mean of the data. The ends of the boxes represent the upper and lower quartiles. The extreme lines represent the minimum and maximum values. Figure created using packages “ggplot2” (version 3.3.5; Wickham, 2016), “ggthemes” (version 4.2.4; Arnold, 2021), and “wesanderson” (version 0.3.6; Ram & Wickham, 2018). *p<0.001. EAS, Expectations Assessment Scale

To summarize, participants’ individual expectations for NIBS as a cognitive enhancement method changed depending on situationally primed expectations, even while controlling for aspects of situation motivation (see Table 3). To identify where these differences existed, we examined Tukey HSD post-hoc comparisons. In the low expectation prime group, composite EAS significantly decreased from baseline (M = 4.616, SE = 0.074) to post-prime (M = 3.204, SE = 0.077; t_{650} = −19.152, p < 0.001). In the high expectation prime group, composite EAS significantly increased from baseline (M = 4.286, SE = 0.076) to post-prime (M = 4.894, SE = 0.079; t_{650} = 8.113, p < 0.001). Participants who read the neutral expectation prime did not significantly change in terms of composite EAS from

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baseline \((M = 4.383, SE = 0.073)\) to post-prime \((M = 4.329, SE = 0.076; t_{650} = -0.748, p = 0.976)\). See Fig. 2 for a visualization of these results. This pattern of our results replicated Rabipour et al.’s (2017) results and aligned with our hypotheses, supporting our claim that expectations are malleable.

We were also interested in possible differences between expectation prime groups for post-prime composite EAS. Notably, we observed lower post-prime composite EAS between the low expectation prime group \((M = 3.204, SE = 0.077)\) and the neutral expectation prime group \((M = 4.329, SE = 0.076; t_{650} = -10.430, p < 0.001)\) as well as the high expectation prime group \((M = 4.894, SE = 0.079; t_{650} = 14.840, p < 0.001)\). Additionally, post-prime composite EAS was lower in the neutral expectation prime group than the high expectation prime group \((t_{650} = 5.090, p < 0.001)\).

We observed mostly similar results when we repeated the 3 × 2 mixed ANOVA for the eight items (i.e., once for each item area), which was not surprising considering the composite EAS was created by averaging these eight item areas. Specifically, according to our corrected alpha threshold, there was not a statistically main effect of time in the “multitasking (i.e., dual-tasking) ability” \((F_{1,650} = 5.456, \eta^2 = 0.001, p = 0.020)\) and “reasoning ability” \((F_{1,650} = 3.567, \eta^2 = 0.005, p = 0.059)\) models. Most importantly to our primary research question, however, the interaction between time and expectation prime was still statistically significant. For additional information, please see https://osf.io/ly5pwr/.

Our results from this analysis align with what Rabipour et al. (2017) found, even with our design changes. Broadly, success ratings for each EAS item area shifted in the direction of the expectation prime. Specifically, our study and Rabipour et al. (2017) both found that across all cognitive domains, success ratings were above neutral for the high expectation prime condition and were below neutral for the low expectation prime condition.

Because we analyzed baseline confidence ratings across each EAS item, we repeated this analysis for participants’ post-prime confidence ratings. Specifically, we assessed differences in confidence levels across each post-prime EAS success rating across the three expectation prime groups by calculating eight \(\chi^2\) tests of association with a corrected alpha of 0.006 \((\alpha = 0.05/8 \times 2\) tests\). For all tests, \(df = 2\) and \(N = 655\). There was a statistically significant association between expectation prime and post-prime confidence ratings for several variables at baseline. To achieve this aim, we repeated the 2 (time: baseline/pre-prime, post-prime) × 3 (expectation prime: neutral, low, high) mixed ANOVA with composite EAS as the dependent variable. We included the 10 psychological factors (intrinsic motivation, identified regulation, external regulation, amotivation, perceived stress, need for cognition, growth mindset, self-efficacy, cognitive failures, attentional lapses) as covariates to determine which psychological factors, if any, might impact the malleability of NIBS expectations (see Table 4 for results).

More important to our primary research question, when considering all 10 psychological factor covariates, there was no main effect of time \((F_{1,642} = 0.701, \eta^2 < 0.001, p = 0.403)\) on composite EAS. However, there was a statistically significant main effect of expectation prime \((F_{2,642} = 31.376, \eta^2 = 0.008, p < 0.001)\) as well as a significant interaction between time and expectation prime \((F_{2,642} = 175.867, \eta^2 = 0.015, p < 0.001)\) on composite EAS, which was similar to what we observed when we investigated the effects of expectation prime and time on composite EAS without including all 10 psychological factors as covariates. Thus, our primary finding, which was that baseline outcome expectations can shift in the direction of primed pessimistic and
optimistic expectations, replicated when accounting for other potential explanations through various psychological factors. Further, there was a significant interaction between time and identified regulation ($F_{1,642} = 10.094, \eta^2 < 0.001, p = 0.002$) on composite EAS, with no other significant interactions between time and the other psychological factors ($F_{range} = 0.003 – 3.320; all \eta^2 < 0.001, all p \geq 0.069$). Based on our pre-registration, we repeated this analysis with one covariate at a time for a total of 10 tests, and these analyses are available at https://osf.io/y5pwr/ for interested readers.

### Discussion

The malleability of expectations may be contributing to the mixed success rates of NIBS cognitive enhancement studies through positive expectancy and placebo and placebo-like effects (Benedetti, 2014; Boot et al., 2013; Braga et al., 2021; Schwarz et al., 2016; Simons et al., 2016), though very few studies have considered this possibility and teased it apart by priming different expectations (Foroughi et al., 2016; Rabipour et al., 2017; Rabipour et al., 2018a; 2018b; 2019). Specifically, if participants are primed to have optimistic outcome expectations of NIBS methods for cognitive enhancement, this may lead to high engagement with the intervention. Likewise, if participants are primed to have pessimistic outcome expectations of NIBS methods for cognitive enhancement, they may not pursue or adhere to such an intervention. In our Registered Report, we sought to research the malleability of expectations for NIBS as a cognitive enhancement method. We conceptually replicated and expanded Rabipour et al. (2017) using a large sample and mixed design. We used a refined version of Rabipour et al.’s (2017) outcome expectations measure that included an additional cognitive domain and focused on CES as a NIBS method. Additionally, we explored how various psychological factors related to outcome expectations to determine if certain characteristics were likelier to influence outcome expectations of CES for cognitive enhancement.

To confirm that our results could be attributed to our manipulation and not preexisting group differences, we first assessed baseline differences. We examined baseline differences among the expectation prime groups across select demographics (i.e., age, gender), outcome expectation success and confidence ratings, and various psychological constructs (i.e., intrinsic motivation, identified regulation, external regulation, amotivation, perceived stress, need for cognition, growth mindset, self-efficacy, cognitive failures, attentional lapses). To re-iterate, demographics were collected prior to exposure to the expectations prime, psychological constructs were assessed after exposure to one of the three expectation primes, and outcome expectation success and confidence ratings were measured before and after exposure to the expectations prime. At baseline, there were differences among the expectation prime groups for two aspects of situational motivation, identified regulation and amotivation.
and we included these variables as covariates in our primary analysis. Our expectation prime groups did not differ in age, gender, all baseline EAS item success and confidence ratings, and the remaining eight psychological factors. Future researchers may wish to include baseline assessments of select psychological factors to observe how priming different expectations can influence short-term changes in situational motivation and other related variables.

In our primary analysis, our results replicated Rabipour et al.’s (2017) results. We found that participants initially had relatively neutral expectations toward CES as a cognitive enhancement method across various cognitive domains. A little more than half of the participants (≤ 64%) in our sample (N = 655) reported that they felt confident in their baseline responses for each EAS item. In contrast, most participants (≥ 83%) in Rabipour et al.’s (2017) sample (N = 428), and particularly the young adult subsample (≥ 74%, n = 300) felt confident in their baseline responses for each EAS item. These findings are interesting considering the past few years have seen reports from companies advertising the increasing benefits of various cognitive enhancement methods, including tES (Simons et al., 2016).

Further, and more critically to our research question, we found that expectations of CES for cognitive enhancement were malleable, even when controlling for relevant aspects of situational motivation. Relative to baseline, outcome expectations substantially decreased or increased after reading primes that set either low or high expectations for CES cognitive enhancement methods, respectively. In contrast, expectations about CES for cognitive enhancement did not change from baseline to post-prime for participants in the neutral expectation prime condition. These patterns of results replicate those of Rabipour et al. (2017), and they also align with related research that shows support for placebo effects (Foroughi et al., 2016; Rabipour et al., 2018b; 2019). There were also significant associations between expectation prime and post-prime confidence ratings on two of the eight EAS items. There were more participants who felt confident in their responses if they read either the low or high expectation prime compared to those who read the neutral expectation prime. Our results imply that the degree of effectiveness of NIBS interventions for cognitive enhancement may be based more on how the interventions were advertised in recruitment flyers or explained during experimenter instructions than on the effects from the interventions. Our results also suggest that using neutral language, especially for participants with relatively neutral expectations about NIBS methods, may be the best option to deter positive and negative expectancy effects of NIBS methods for cognitive enhancement.

To better understand if certain characteristics influence the potential responsiveness to cognitive enhancement, we also explored how various psychological factors, including situational motivation, perceived stress, cognition-related beliefs, and perceptions of real-world cognition, might interact with outcome expectations. Outcome expectations were related to all four areas of situational motivation (i.e., intrinsic motivation, identified regulation, external regulation, amotivation), which aligns with past research (Jones et al., 2015; Katz et al., 2017; Rabipour et al., 2018b). Outcome expectations were also related to cognition-related beliefs (i.e., need for cognition, growth mindset, self-efficacy), but not perceived stress and perceptions of real-world cognition (i.e., cognitive failures, attentional lapses). More importantly, we found that there was still a significant interaction between expectation prime and time when accounting for these various psychological factors. Thus, while these psychological factors might play a role in influencing expectations about NIBS malleability, the influence appears to be relatively minimal compared to expectation primes.

Several limitations could have influenced our results. These limitations lend themselves nicely as future directions for researchers who wish to further investigate outcome expectations of cognitive enhancement through NIBS. First, because participants were repeatedly exposed to the EAS (i.e., baseline/pre-prime, post-prime), they may have been aware that they were being primed and that we were interested in their outcome expectations. However, our change to a between-subjects design from Rabipour et al.’s (2017) within-subjects design helps lessen the likelihood of such carryover effects. Future outcome expectations research should include questions that assess participant bias to invest more confidence in this claim.

Further, our methodology was entirely based on self-report measures and this limits our findings’ generalizability. For instance, we asked participants if they had experience or familiarity with brain stimulation, and 13% (n = 85) of participants answered “yes.” Some of those who answered “yes” provided optional text explanations and clarified that their experience or familiarity with brain stimulation included puzzles, autonomous sensory meridian response (ASMR), and attention-deficit/hyperactivity disorder (ADHD) testing. However, these examples do not align with our operationalization of brain stimulation, meaning that it is likely less than 13% of our sample had neither experience nor familiarity with brain stimulation. The small number of participants who had experience or familiarity with brain stimulation could potentially explain why we did not observe more confidence in baseline EAS response ratings, especially since we observed lower proportions than Rabipour et al. (2017). Future studies should recruit more participants with experience or familiarity with brain stimulation and test if this accounts for differences in outcome expectations.

Critically, self-reported expectations of outcomes may not directly relate to actual outcomes. Outcomes might resolve differently for in-person studies with NIBS methods that...
employ active and sham stimulation (for studies, see Rabipour et al., 2018b, 2019). Furthermore, it is possible that any impact of expectations on intervention outcomes could be minimized by standardizing recruitment materials, consent forms, and participant-facing instructions, as well as using active control conditions that deliver stimulation of equal duration and magnitude to brain regions not targeted by the research question(s). Accompanying a cognitive training intervention with NIBS could further influence if expectations of outcomes align with actual outcomes, even when controlling for language used during recruitment, consenting, and instruction. Given the popularity of working memory training and recent discussion of its potential placebo effects (Baniqued et al., 2015; Boot et al., 2013; Foroughi et al., 2016; Melby-Lervåg et al., 2016; Rabipour & Raz, 2012; Schwaighofer et al., 2015; Shipstead et al., 2012; Tsai et al., 2018; Vodyanyk et al., 2021; Wiemers et al., 2019), we believe there is an acceptable, sound theory for future work to include a working memory item in the EAS and explore how outcome expectations and NIBS influence working memory training gains over time and transfer. We expect that our results, as well as others’ (Foroughi et al., 2016; Rabipour et al., 2017, 2019; Rabipour et al., 2018b), would largely replicate, and cognitive enhancement training gains would follow the direction of the expectation prime.

Overall, conceptually replicating and extending Rabipour et al.’s (2017) research contributed to a more holistic, mechanistic understanding of how various psychological factors and situational contributors might play a role in influencing expectations, and the outcomes of such expectations, surrounding NIBS cognitive enhancement methods. Our research could potentially inform the design of NIBS protocols by shaping the approaches of those who wish to increase participant expectations of NIBS to improve cognitive enhancement and those who want to decrease or neutralize participant expectations of NIBS to reduce possible placebo effects. Experimenter who research NIBS for cognitive enhancement should be wary of how their behavior can influence participants’ behavior and consider how participant characteristics, such as motivation for pursuing cognitive enhancement, may shape how expectations potentially influence outcomes.

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**Data availability** This Registered Report was accepted in principle prior to data collection (https://osf.io/pysnu/). All data and materials are available on the Open Science Framework (OSF) at https://osf.io/c4kfyl/.

**Code availability** Data processing (https://osf.io/9ab6w/) and analysis (https://osf.io/y5pwr/) code are available on OSF.

**Declarations**

**Ethics approval** This study was approved by the Tufts University Institutional Review Board (#1908026) and was conducted in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

**Consent to participate** Freely given; informed consent to participate in this study was obtained from participants.

**Consent for publication** We obtained consent from participants to publish their de-identified data prior to submitting this paper to a journal, and this data is available on OSF (https://osf.io/5bwec/).

**Conflict of interest** The authors declare no competing interests.

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