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1   **TITLE:**
2   Transcranial direct current stimulation (tDCS) for memory enhancement
3
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17 **SUMMARY:**
18 A protocol for memory enhancement by using transcranial direct current stimulation (tDCS)
19 targeting dorsolateral prefrontal and posterior parietal cortices, as core cortical nodes within
20 hippocampo–cortical network, is presented. The protocol has been well evaluated in healthy-
21 participant studies and is applicable to aging and dementia research as well.
22

23 **ABSTRACT:**
24 Memory enhancement is one of the great challenges in cognitive neuroscience and
25 neurorehabilitation. Among various techniques used for memory enhancement, transcranial
26 direct current stimulation (tDCS) is emerging as an especially promising tool for improvement of
27 memory functions in a non-invasive manner. Here, we present a tDCS protocol that can be
28 applied for memory enhancement in healthy-participant studies as well as in aging and
29 dementia research. The protocol uses weak constant anodal current to stimulate cortical
30 targets within cortico-hippocampal functional network engaged in memory processes. The
31 target electrode is placed either on the posterior parietal cortex (PPC) or the dorsolateral
32 prefrontal cortex (DLPFC), while the return electrode is placed extracranially (i.e., on the
33 contralateral cheek). In addition, we outline a more advanced method of oscillatory tDCS,
34 mimicking a natural brain rhythm to promote hippocampus-dependent memory
35 functions, which can be applied in a personalized and non-personalized manner. We present
36 illustrative results of associative and working memory improvement following
37 single tDCS sessions (20 minutes) in which the described electrode montages were used with
38 current intensities between 1.5 mA and 1.8 mA. Finally, we discuss crucial steps in the protocol
39 and methodological decisions that must be made when designing a tDCS study on memory.
40

INTRODUCTION:

Memory plays a vital role in everyday functioning as it enables one to remember information about people and places, recall past events, learn new facts and skills, as well as to make judgments and decisions. Here we focus on two types of memory – working memory (WM) and associative memory (AM). WM provide us with the ability to temporarily maintain and store information for ongoing cognitive processing [1], while AM enables us to remember multiple pieces of experience or information bound together. Therefore, these two types of memory underline almost all daily activities. Unfortunately, memory is one of the most vulnerable functions as it declines with normal ageing as well as due to various pathological states and conditions. Both WM and AM decline is prominent in mild cognitive impairment [2,3] and dementia [4,5] as well as in normal ageing [6,7]. Since memory deficits are associated with a high disease burden level [8,9] and significantly affect quality of life [10–13], there is a growing need for novel approaches to prevention and treatment of memory decline.

Transcranial direct current stimulation (tDCS) is a promising tool for tackling memory decline [14–16] and gaining better understanding of brain functions in general [17]. tDCS is a non-invasive brain stimulation technique that uses weak electric currents (usually between 1 mA and 2 mA) to modulate brain activity by affecting neuronal membrane excitability. The effects of tDCS are polarity-dependent, such that anodal stimulation increases while cathodal decreases neuronal excitability. Namely, anodal tDCS increases the likelihood for action potentials to fire through depolarization of neuronal membranes, thus facilitating spontaneous brain activity under the anode [18]. Moreover, it is shown that the effect of increased activation does not remain localized but tends to spread to other functionally connected areas of the central nervous system. Anodal tDCS is thus expected to promote cognitive functions that rely on targeted brain regions and functionally interconnected brain areas, while cathodal tDCS is expected to have the opposite effect.

The tDCS has several advantages over other brain stimulation techniques: (1) tDCS is safe, i.e., does not pose health risks and does not produce any negative short or long term structural or functional changes [19]; (2) tDCS is characterized by highest tolerability among brain stimulation techniques as it causes minimal discomfort to participants in a form of a mild tingling and itching sensations under the stimulating electrodes [20]; (3) tDCS is cost-effective – the price of tDCS devices and application are ten to hundred times lower than other treatment options, which makes it attractive for patients and healthcare system; (4) tDCS is easy to use, and therefore has a high potential to be applied even in home-based settings, which can lead to higher compliance of patients and reduced cost for medical staff and facilities.

The main challenges for using tDCS for memory enhancement are finding the optimal electrode montage and stimulation protocol that will produce reliable effects on memory. Here we use the term *electrode montage* to refer to the configuration and the positions of the electrodes (i.e., the placement of the target and reference (return) electrode). Due to the nature of the electrical fields, the reference (return) electrode is not neutral – it has the polarity opposite to the target electrode – and thus can also exercise biological (neuromodulatory) effects on the underlying neural tissue. Therefore, careful choice of the reference electrode is essential for

85   avoiding unwanted additional effects of the stimulation.
86
87   When using the term *stimulation protocol,* we refer to the tDCS parameters such as the
88   duration and the intensity of the current being applied as well as the way current intensity
89   changes over time (i.e., whether the intensity is constant throughout the stimulation or
90   changes following a sinusoidal waveform with certain amplitude and frequency). Different
91   stimulation protocols can be applied using the same electrode montage, and the same protocol
92   can be used across different montages.
93
94   To optimize the electrode montage, we look at the function-relevant brain areas and how the
95   electric fields induced by various positions of the electrodes would affect those brain areas and
96   consequentially cognitive functions. Several different cortical and subcortical structures play a
97   significant role in memory functions - including areas of the frontal, temporal, and parietal
98   cortex. Namely, WM is supported by a widespread neural network that includes dorsolateral
99   (DLPFC) and ventral lateral prefrontal cortex (VLPFC), premotor and supplementary motor
100   cortices, as well as posterior parietal cortex (PPC)[21]. For AM and episodic memory in general,
101   structures within medial temporal lobe are essential [22]. However, associative areas of the
102   parietal, frontal, and temporal cortices, with their convergent pathways to the hippocampus
103   also play a significant role. Due to its anatomical position, the hippocampus cannot be directly
104   stimulated using tDCS, and thus the enhancement of hippocampus-dependent memory
105   functions is done using the cortical targets with high functional connectivity to hippocampus
106   such as posterior parietal cortex. For these reasons, DLPFC and PPC are most frequently used as
107   stimulation targets to enhance memory. Positioning of the electrodes can be further refined
108   based on current flow modeling [23] and validated in studies that combine tDCS with
109   neuroimaging techniques[24].
110
111   The most usual *stimulation protocol* is a constant anodal current of 1-2 mA that lasts between
112   10-30 minutes. The assumed mechanism behind this protocol is that the electrode with a
113   positive charge will increase the excitability of the underlying cortical tissue which will than
114   result in enhanced subsequent memory performance. Unlike the constant anodal tDCS, where
115   current intensity stays the same during the whole stimulation period, in the oscillatory tDCS
116   protocol the intensity of the current fluctuates at the given frequency around a set value.
117   Therefore, this type of protocol modulates not only excitability but also entrains neural
118   oscillations of the relevant brain areas. It is important to note that for both constant and
119   oscillatory tDCS the electrodes retain the same current polarity for the whole duration of the
120   stimulation.
121
122   Here we present tDCS montages that target nodes within fronto-parieto-hippocampal network
123   to promote memory – both WM and AM: specifically, two electrode montages with the target
124   electrode over either left/right DLPFC or left/right PPC. In addition to constant anodal tDCS
125   protocol we outline a theta oscillatory tDCS protocol.
126
127   **Study design**
128   Before providing a detailed guide on how to use tDCS for memory enhancement, we will

129   outline a few essential properties of the experimental design that are important to consider
130   when planning a tDCS study on memory.
131
132   *Sham control*
133   To assess the effects of tDCS on memory, the study needs to be sham controlled. This implies
134   that in one of the experimental conditions the protocol resembles a real stimulation session,
135   but no treatment is given. This fake or sham session serves as a reference point to compare
136   performance following real tDCS and make inferences about its effectiveness. Commonly, in the
137   sham protocol the current is applied only for a brief period – usually up to 60 seconds at the
138   beginning and at the end of the sham stimulation as a ramp-up followed by immediate ramp–
139   down (i.e., fade-in/fade-out, up to 30 seconds each) fashion. This way it is ensured that the
140   duration of the stimulation is insufficient to produce any behavioral or physiological effects.
141   Since local skin/scalp sensations are usually most pronounced at the beginning and at the end
142   of stimulation (due to changes in the current intensity), the sensations induced in all protocols
143   are comparable and difficult to distinguish [25]. This way, the participant is blinded on whether
144   the stimulation is real or not, which is especially important in within-subject designs.
145
146   In addition to sham-control, to assess the specificity of the effects of oscillatory protocols, it is
147   advisable to have an *active control condition*, too. For instance, the active control for oscillatory
148   protocol can be constant anodal stimulation of the same intensity[26,27], or oscillatory stimulation
149   in different frequency e.g. theta *vs* gamma [28].
150
151   *Within- or between-subjects design*.
152   In within-subjects design each participant undergoes both real and sham tDCS, while in
153   between-subjects design one group of participants receives real, and the other group receives
154   sham tDCS. The main advantage of within-subject design is better control of subject-specific
155   confounds. That is, individual differences in anatomy and cognitive abilities are best controlled
156   for when each participant is compared to their self. However, since within-subject design needs
157   to be applied in cross-over fashion (i.e., half of the participants receive real tDCS in the first
158   session and sham in the second session, while the other half of participants of receive sham
159   first and real tDCS second) this design may not be optimal for clinical and training studies as
160   well as studies involving several tDCS sessions over consecutive days, because crossover design
161   may result in unequal baselines between crossover arms. Therefore, within-subject design is
162   suited the best when assessing either behavioral or physiological effects of a single tDCS
163   session, and when unequal baselines are not considered an issue for the research hypothesis. In
164   within-subject design assessing the effects of single tDCS session, it is a good practice to keep 7
165   days between real and sham tDCS session to avoid carryover effects (however some studies
166   suggest even shorter wash-out periods do not significantly affect the outcomes [29,30]) and to use
167   parallel forms of memory tasks in counterbalanced order to minimize training and between-
168   session learning effects.
169
170   When between-subjects design is used, the control group should be carefully matched for
171   baseline performance, as well as other relevant characteristics known to be of relevance for
172   tDCS effectiveness. Random group assignment may not be the best approach in small sample

173 sizes (e.g., <100) as it may lead to suboptimal matching. In either case, baseline performance
174 should be accounted for in statistical analysis.

176 *Sample size.*
177 One of frequently asked questions is "how many participants does one need to detect tDCS
178 effects". The answer to this question depends on several aspects of the study including
179 experimental design, expected effects sizes, type of statistical analysis, etc. The sample sizes in
180 the brain stimulation experiments are often too small, and it is estimated that studies in this
181 field miss around 50% of true positive results because they are underpowered [31]. Power
182 analysis enables determining adequate sample size for each specific experiment based on the
183 study design and expected effect size for planned statistical analysis. The power analysis can be
184 performed in R environment or using free specialized software such as G*Power [32], and it
185 should always be performed *a priori* (i.e., before the experiment). The power should be set at
186 >.80 (ideally.95) and expected effect size on memory tasks following a single tDCS session is
187 usually between.15-.20 (η^2) i.e., Cohen f 0.42-0.50. Therefore, one typically needs to enroll 20-
188 30 participants in total for within-subject experiment and 30-40 participants per group for
189 between-subject study, to achieve satisfactory power and thus diminish type II error. However,
190 the sample size depends on the number of other factors including the planned analysis, and
191 sensitivity of the behavior measures that are used. Therefore ideally, one would run an initial
192 experiment to understand the effect sizes for the specific design and use those data as an input
193 for power analysis. However, it is important to note that running a pilot experiment on just a
194 few participants will lead to faulty and unreliable estimates of the effect sizes. Therefore, if
195 resources are limited it is better to rely on the previous studies with comparable outcomes, and
196 take slightly more conservative approach i.e., by estimating for somewhat smaller effect sizes
197 than reported in the literature.

199 *Outcome measures*
200 To assess the effectiveness of tDCS on memory one needs to select adequate behavioral tasks.
201 In fact, the choice of the memory task is one of the crucial aspects of the study design, because
202 the ability to detect the tDCS effect directly depend on the sensitivity of the task. The challenge
203 here is that most standardized memory assessment tools or classical neuropsychological tasks
204 may not be sensitive enough to detect tDCS effects in specific populations. Furthermore, most
205 of the standardized tasks are not available in two or more parallel forms and therefore cannot
206 be used in within-subjects designs. For that reason, most of the tDCS memory studies use
207 custom-build tasks. When designing or selecting outcome measure one should ensure that the
208 task is: (1) focal/selective measure of the memory function of interest; (2) sensitive (i.e., that
209 the scale is fine enough to detect even small changes); (3) challenging for the participants (i.e.,
210 that the task difficulty is sufficient and thus to avoid celling effects); (4) reliable (i.e., that the
211 measurement error is minimized as much as possible). Therefore, one should use empirically
212 validated strictly parallel forms of memory tasks, which have a sufficient number of trials – both
213 to ensure sensitivity of the measure as well as to maximize its reliability. Ideally, the tasks
214 should be pre-tested on a group sampled from the same population as the experiment
215 participants to ensure that maximum performance is not achievable, and that the task-forms
216 have equal indices of difficulty. Finally, it is best to use computerized tasks whenever possible

217 as they allow for controlled duration and precise timing. This way researchers can ensure that
218 all participants undergo memory assessment at the same time in respect to the timing of
219 stimulation (either during or following tDCS). The duration of each task or task block should not
220 be longer than 10 minutes, to avoid fatigue and fluctuation in attention levels; the cognitive
221 assessment should not be longer than 90 minutes in total (including tasks both during and after
222 tDCS).
223
224 **PROTOCOL**
225
226 This procedure has been approved by the Institutional Ethics Committee and is in line with the
227 Declaration of Helsinki and guidelines for human research.
228
229 **1.   Materials**
230
231 NOTE: For each tDCS session prepare the following materials (**Figure 1**).
232
233 1.1.   Obtain a tDCS device – use only a battery driven tDCS device or a mains-connected
234 optically isolated tDCS device. The device should function as a constant current stimulator with
235 a maximum output limited preferably to a few milliampere range. The device must have
236 regulatory approval for human use.
237
238 1.2.   Obtain rubber electrodes – use either 5 cm x 5 cm square-shaped or 25 cm^2 round-
239 shaped electrodes. These electrodes will have the current densities between 0.06 mA/cm^2 and
240 0.08 mA/cm^2 for currents of 1.5 mA-2 mA, respectively.
241
242 1.3.   Prepare sponge pockets that fit the rubber electrodes. If the sponge pocket is too large
243 it will increase the contact surface to the skin.
244
245 1.4.   Prepare saline solution (standard 0.9% NaCl).
246
247 1.5.   Prepare alcohol (70%).
248
249 1.6.   Obtain an adjustable silicone cap – head straps can be used as well, however EEG
250 silicone caps can be better adjusted to the size and the shape of participants' head and are
251 therefore more comfortable for electrode placement.
252
253 1.7.   Obtain measuring tape (flexible; plastic or ribbon).
254
255 1.8.   Obtain a skin marker – skin marker pencils or various makeup products (e.g., eye pencil
256 or eyeshadow crayon), the later can be even more convenient as they are dermatologically
257 tested and easily removable.
258
259 1.9.   Obtain cotton pads.
260

261   1.10.   Obtain comb and single-use mini silicon hair bands.

262

263   1.11.   Obtain a syringe or plastic pipette.

264

265   1.12.   Prepare a protocol sheet – fill-in form for basic information about the session i.e.,
266   participants ID, study ID, date, times, notes, etc (see **Appendix** for an example).

267

268   1.13.   Prepare a table with pre-calculated head measures to help with electrodes' placement.

269

270   NOTE: To speed-up the process and to reduce the possibility for errors, it is advisable to have
271   this table ready in advance. The measurement is based on 10-20 EEG electrode placement
272   system; the values used for calculations are nasion-inion/left-right-preauricular distances (see
273   below). The table gives 20% values for a range of distance values. We have found it as the most
274   convenient to have the table embedded into the protocol sheet (Appendix).

275

276   1.14.   Prepare questionnaires. For each session, collect data on sensations and side effects
277   before and after tDCS; sensations and the level of (un)pleasantness during tDCS; mood and
278   general subjective state i.e., freshness/tiredness.

279

280   [Place **Figure 1** here].

281

282   **2.   Programing stimulation protocols**

283

284   NOTE: Exact steps in programming tDCS protocol differ across tDCS systems/devices. However,
285   all tDCS devices provide basic features – the ability to produce constant current with desired
286   stimulation intensity, the ability to gradually ramp up and down, and a method to set the
287   duration of stimulation. The more advanced protocols such as theta-oscillatory tDCS require
288   devices/systems that allow for custom-built stimulation protocols.

289

290   2.1.   Constant anodal tDCS

291

292   2.1.1.   Define the standard constant anodal tDCS protocol (**Figure 2A**) as: (1) fade-in period of
293   30 seconds, when current intensity is gradually ramped up from 0 mA to the target intensity
294   (we typically use 1.5 mA, but other intensities can be used as well, providing they stay within
295   safety limits); (2) stimulation period during which the constant current of the target intensity
296   (e.g., 1.5 mA) is delivered; and (3) fade-out period of 30 seconds when current intensity is
297   gradually decreased to 0 mA.

298

299   [Place **Figure 2** here].

300

301   2.2.   Theta oscillatory tDCS

302

303   2.2.1.   Theta-oscillatory tDCS delivers current of varying intensity but does not switch polarities
304   (**Figure 2B**). Therefore, define the waveform in which the current is delivered as following: (1)

305 fade-in period of 30 seconds, when current intensity is gradually ramped up from 0 mA to the
306 target intensity (e.g., 1.5 mA); (2) the stimulation period of 19 minutes in which the current
307 oscillates around the target intensity within a pre-defined amplitude range (we use oscillations
308 of ± 0.5 mA of the target intensity) in a selected frequency (we typically use 5 Hz frequency as
309 representative for theta rhythm); and (3) fade-out period of 30 seconds to bring the current
310 intensity to 0 mA.

312 NOTE: This protocol can be generated by any experimental control software (e.g., CED Signal)
313 and delivered through an intelligent interface (e.g., CED 1401 range of devices) that is
314 compatible with tDCS device which is to be used. Some more advanced dedicated transcranial
315 electric stimulation (tES) systems besides tDCS can deliver alternating current (tACS) and
316 random noise stimulation (tRNS) too. They can also be used to generate the oscillatory tDCS
317 protocol. For example, in StarStim the theta-oscillatory tDCS protocol are defined as a linear
318 combination of tDCS (1.5 mA) and tACS (±0.5 mA, 5 Hz). This type of protocol can be
319 personalized in a sense that not all participants receive oscillatory stimulation in the same
320 frequency (i.e., 5 Hz), but that the frequency is adjusted to the dominant frequency within
321 theta band for each person (e.g., Person 1: 5 Hz, Person 2: 6 Hz, Person 3: 4.5 Hz, etc.).

323 2.3.   Sham tDCS

325 2.3.1. Use a sham protocol with the same duration as constant/oscillatory tDCS (**Figure 2C**).
326 Namely, define it as: (1) first fade in/out period in which the current is gradually ramped up to
327 target intensity (e.g., 1.5 mA) and gradually ramped down to 0 mA during the first 60 seconds
328 (2) 18 minutes of 0 mA, and (3) the second fade in/out period which again lasts 60 seconds.

330 NOTE: An alternative approach would be to use very low current intensity over the entire
331 stimulation period (20 min). This type of sham protocol is programmed the same as the anodal
332 stimulation (only the current intensity is set to (0.1 mA) and is designed to produce cutaneous
333 sensations but the intensity is too week to produce any physiological effects [33].

335 **3.   Electrode placement (Figure 3)**

337 3.1.   DLPFC electrode montage: For stimulation of the DLPFC, place the target (anodal)
338 electrode on either F3 (left) or F4 (right) of the international 10-20 EEG system. Place the return
339 electrode (cathodal) on the contralateral cheek - i.e., right cheek for F3 anode and left cheek for
340 F4 anode.

342 3.2.   PPC electrode montage: For stimulation over PPC, place the target (anodal) on either P3
343 (left) or P4 (right) of the international 10-20 EEG system. Place the return electrode (cathodal)
344 on the contralateral cheek same as in DLPFC montage.

346 3.3.   The target electrode placement

347

3.3.1. To locate **F3** on participants' head

3.3.1.1.   Use the measuring tape to measure the distance between nasion (the deepest point of the nasal bridge) and inion (the most pronounced point of the external occipital protuberance) going over the top of the head. Mark the halfway distance with the skin marker with a thin line.

3.3.1.2.   Measure the distance between the ears (use preauricular points as references) going over the top of the head and mark the halfway distance with a thin line.

3.3.1.3.   Find the vertex or midline central position, referred as Cz, at the intersections of the two midlines. Mark it clearly with the skin marker.

3.3.1.4.   Measure again the nasion-inion distance, but this time going over Cz, and note the distance as measure A. Measure again the distance between the ears, this time going over Cz, and note the distance as measure B.

3.3.1.5.   Calculate 20% of distance A, and 20% of distance B (or see Protocol sheet for pre-calculated values).

3.3.1.6.   Move 20% of distance A forward from Cz along the nasion-inion line to reach Fz (midline frontal) and mark the spot.

3.3.1.7.   Move 20% of distance B leftward from Cz along the inter-auricular line to reach C3 (left central) and mark the spot.

3.3.1.8.   Move 20% forward form **C3** (in parallel with the nasion-inion line), and 20% leftward form Fz (in parallel with the inter-auricular line), to reach F3 at the intersection. Mark **F3** with the skin-marker and place the center of the electrode at the spot.

3.3.2. To locate **F4,** follow the same procedure only on the right side of the head.

3.3.3. To locate **P3** on participants' head

3.3.3.1.   Follow the steps 3.3.1.1-3.3.1.5 as outlined above (find Cz, note distance A and B, calculate 20%).

3.3.3.2.   Move 20% of distance A backward from Cz along the nasion-inion to reach Pz (midline parietal) and mark the spot.

3.3.3.3.   Move 20% of distance B leftward from Cz along the inter-auricular line to reach C3 and mark the spot.

391 3.3.3.4.   Move 20% backward from C3 (in parallel with the nasion-inion line), and 20%
392 leftward from Pz (in parallel with the inter-auricular line), to reach **P3** at their intersection.
393 Mark **P3** with the skin-marker and place the center of the electrode at the spot.

395 3.3.4. To locate **P4**, follow the same procedure only on the right side of the head.

397 3.4.   Return electrode placement

399 3.4.1. After securing the target electrode with the adjustable silicon cap (see step-by step
400 procedure), insert the return electrode below the chin band to secure the contact of the
401 electrode with the contralateral cheek.

403 **4.   Step-by-step procedure**

405 4.1.   Before the tDCS session

407 4.1.1. Check if each participant satisfies the inclusion criteria as defined in ethical approval for
408 the study (see **Appendix** for the most common inclusion/exclusion criteria).

410 4.1.2. Ask the participant to fill in the Participant information sheet (including all the relevant
411 information such as age, gender, nicotine/alcohol consumption, etc.[34]).

413 4.1.3. Following the institutional review board ethical guidelines, and ask participant to sign
414 informed consent. Use this opportunity to explain the basic aspects of the procedure they will
415 undergo and answer any questions the participants may have.

417 4.1.4. Depending on the study design, perform baseline cognitive assessment (memory and/or
418 other cognitive functions).

420 4.2.   tDCS set-up and stimulation

422 4.2.1. Seat the participant comfortably in a chair.

424 4.2.2. Ask participant to fill out pre-tDCS sensations checklist and to report on overall state
425 (i.e., current mood; freshness/tiredness – these can be assessed as either as a single Likert-type
426 item or using standardized questionnaires such as Brief Mood Introspection Scale [35]).

428 4.2.3. Take head measures using a measuring tape.

430 4.2.4. For locating the DLPFC or PPC follow the procedure described above (electrode
431 placement). Write down the measures in the Protocol sheet for each participant. These can be
432 used to check against when taking measurements in subsequent sessions.

434 4.2.5. To increase conductance, move away participant's hair from stimulation site (use comb
435 and hair bands for participants with long hair).

436

437 4.2.6. Inspect for any signs of skin damage at the place of stimulation. Avoid positioning
438 electrodes over damaged skin.

439

440 4.2.7. Clean the surface of the skin where electrodes will be placed using alcohol-soaked
441 cotton pads to remove grease, dirt, etc. and let it dry (use a makeup removal product if the
442 participant has heavy makeup on the cheek).

443

444 4.2.8. Put the silicon cap on the participant's head and secure it with the chinstrap. Do not
445 make the cap tight (this will be done later).

446

447 4.2.9. Soak the sponge pockets with saline solution and put the electrodes inside them. The
448 sponges should be moist but not dripping; usually 10-15 mL of saline solution per sponge is
449 enough. If the sponges are too dry this will cause high resistance and result in poor
450 conductivity, even losing the circuit connection.

451

452 NOTE: Most of the tDCS devices have the resistance indicators; however, the sponges should be
453 occasionally inspected for moisture. On the other hand, if the sponges are excessively wet it
454 can cause the current to shift across the head during stimulation. It is recommend having
455 sponges medium wet and use a syringe to add more saline solution during the experiment if the
456 sponges become too dry.

457

458 4.2.10. Put the sponge electrode under the silicon straps and position the center of the target
459 electrode on the marked head-location. Set the return electrode on the contralateral cheek.
460 Use the silicon straps to adjust the cap to the participant's head-size and shape. The cap should
461 be tight so the electrodes cannot move, but still comfortable for the participant.

462

463 4.2.11. Turn on the stimulator, select and run predefined tDCS protocol (active anodal
464 stimulation or sham).

465

466 4.2.12. Ask the participant to relax and let them report how they feel during the first few
467 minutes of stimulation (1-3 minutes). Explain that the sensations will slowly fade away as they
468 get used to it or when they start focusing their attention on some other activity.

469

470

471 4.2.13. To avoid unstructured activities that can interfere with the stimulation effects, use light
472 cognitive engagement during tDCS. For example, participants can perform practice trials of
473 cognitive tasks or engage in easy memory games during stimulation (starting after 3-5 minutes
474 of stimulation). This type of cognitive engagement during stimulation has the potential to
475 promote tDCS effects and will help participants to keep the mind off the tDCS-induced skin
476 sensations.

477

478 4.2.14. Ask the participant to report how they feel multiple times during stimulation (e.g., to
479 report the level of unpleasantness on a 10-point scale every 5 minutes of stimulation, 1 -
480 completely absent, 10 - very intensive). Higher levels of unpleasantness (>6) could be expected
481 during fade-in fade-out periods in some participants. If the level of unpleasantness remains
482 high after 5 minutes abort the stimulation.

484 4.2.15. After the pre-defined protocol run has elapsed, turn off the stimulator.

486 4.2.16. Remove the sponge electrodes first, and then remove the silicon cap.

488 4.2.17. Ask the participant to fill out post-tDCS sensations checklist and to report for any side
489 effects not already listed.

491 4.2.18. Clean the skin on the places where it was marked and inspect the skin for any changes.
492 If there is a skin reaction (e.g., local vasodilation i.e., skin redness on the cheek), monitor as it
493 fades away as it is usually a transient reaction in participants with sensitive skin, and should
494 disappear within 10-15 minutes.

496 4.3.   Memory assessment

498 4.3.1. To standardize the assessment across participants, use computerized assessment tools
499 i.e., memory tasks with automatic scoring. Several WM tasks (e.g., verbal and spatial 3-back
500 task) and AM tasks (verbal paired learning; face-word cued recall, object location, etc.) can be
501 found here: https://osf.io/f28ak/?view_only=f8d5e8dd71d24127b3668ac3d8769408

503 4.3.2. To evaluate the specificity of tDCS effects on memory it is advisable to include control
504 task(s) i.e., tasks tapping other cognitive or motor function.

506 4.4.   Ending the experimental session/study

508 4.4.1. After the (last) experimental session in the study ask participant to try to guess the
509 sessions in which they have received real and sham stimulation. Note all responses and see
510 whether obtained proportions are higher than chance probability. If not, the blinding was
511 successful. If participants were able to differentiate real from sham stimulation analyze the
512 data for those that guessed correctly and those that did not to check if the unsuccessful
513 blinding affected the tDCS effects.

515 4.4.2. In line with ethical guidelines, debrief the participants in detail after their involvement is
516 completed.

518 4.5.   After the experimental session

520 4.5.1. Wash the sponges with running water and soap so that the saline solution is fully
521 washed away. Let the sponges to dry completely before putting them away.

522
523   4.5.2.   Use warm water and alcohol to clean all reusable materials including comb, silicone cap
524   and measuring tape.
525
526   4.5.3.   Make notes on all unusual, unexpected, or unplanned events that might have happened
527   during the session – including any equipment malfunctions, relevant comments made by the
528   participant, interruptions, etc.
529
530   **REPRESENTATIVE RESULTS:**
531   The described protocol has been successfully used to enhance memory performance in several
532   studies in our laboratory. However, similar protocols have been used in other research
533   laboratories as well (e.g., see [36,37]).
534
535   When it comes to working memory, our results have shown that 20-minutes of right frontal
536   tDCS (F4 location; constant current of 1.8 mA) enhanced verbal WM, while the same
537   stimulation protocol applied over left parietal cortex (P3 location) resulted in better spatial WM
538   performance. In contrast, no significant effects were found when the same stimulation protocol
539   was applied over the left frontal (F3) and right parietal (P4) cortices. **Figure 4** shows the
540   representative results of modeling of the electric field generated by tDCS as well as the
541   performance measures following active and sham tDCS based on the data reported in Živanović
542   et al., 2021[38].
543   [Place **Figure 4** here].
544
545   The effects of parietal tDCS on associative memory have been consistent and robust. That is, in
546   the series of within-subject experiments we have shown that 20 minutes of tDCS over left PPC
547   (F3 location; constant current of 1.5 mA) improves memory for face-word associations [27,39,40].
548   **Figure 5** shows representative task and results. In addition, comparable effects were observed
549   on AM task assessing the object-location associations when right PPC (P4 location) is stimulated
550   using the same constant tDCS protocol [40].
551
552   [Place **Figure 5** here].
553
554   The more advanced protocols such as theta-oscillatory tDCS have been less extensively studied,
555   however the study by Lang and colleagues [26] as well as recent study conducted in our
556   laboratory [27] showed improvement in face-word AM following theta-oscillatory tDCS protocol in
557   comparison to sham. The animated figure shows simulation of the electric field induced by
558   theta oscillatory tDCS over left PPC.
559
560   [Place **Video 1** here].
561
562   **FIGURE AND TABLE LEGENDS:**
563   **Figure 1: Materials for tDCS experiment (see text for details).** 1) tDCS device; 2) electrodes; 3)
564   sponges; 4) saline solution; 5) alcohol; 6) silicone cap; 7) measuring tape; 8) skin pencil; 9)
565   cotton pads; 10) combs and silicon hairbands; 11) syringe

566

Figure 2: tDCS protocols: (A) Constant anodal tDCS; (B) Theta oscillatory tDCS; (3) Sham tDCS.
Fade in period is marked orange; fade out period is marked green.

Figure 3: Electrode placement scheme.

Figure 4: (A) Effects of constant anodal tDCS of left PPC (P3-contralateral cheek montage) on spatial working memory performance (spatial 3-back task); (B) Effects of constant anodal tDCS of right DLPFC (F4-contralateral cheek montage) on verbal WM performance (verbal 3-back task). The figure shows simulation of electric fields induced by tDCS, outline of the task trials, and the within-subjects performance across active and sham condition (the values are centered to the order of the session to account for counterbalancing i.e., positive values indicate above-average performance, while negative values indicate below average performance at session). The simulation of local electric fields generated by the electrode set up is performed using COMETS2 MATLAB toolbox [41].

Figure 5: Effects of constant anodal tDCS of left PPC (P3-contralateral cheek montage) on associative memory performance (A) Face-word pairs task; (B) Effects of constant anodal tDCS of left PPC (P3-contralateral cheek montage) on associative memory performance (proportion of correctly recalled words on cue).

DISCUSSION:
The outcome of the tDCS study on memory depends on number of factors, and some of which e.g., homogeneity/heterogeneity of the sample, sufficient statistical power, the difficulty of the memory tasks and motivation of the participants have been previously discussed (see Berryhill, 2014). Several excellent papers on tDCS method, as well as more general tutorials on the application of tDCS to study cognitive functions are available and can be well applied to the memory research too (see[17,43–47]). Here we will focus on the aspects of the protocol which, based on our experience, are relevant but often overlooked or not discussed in sufficient detail elsewhere.

Placement of the return electrode. It is important to keep in mind that the return electrode is not passive but negative-polarity terminal (i.e., cathode). Therefore, it can induce physiological effects that are opposite to the target electrode. Furthermore, the current flow, depends on the positioning of the return as much as it depends on the target electrode. Moreover, since the current flows along the path of the least resistance, if the anode and cathode are located too close to each other, the current may flow only over the skin surface and/or through the cerebrospinal fluid between the electrodes, thus leaving the cortical tissue unaffected. For these reasons, the careful choice of the return electrode is as relevant as the position of the target electrode. There is meta-analytic evidence to suggest that extracranial cathodes are more likely to produce significant effects [48]. Positioning of the return electrode on contralateral cheek for memory enhancement was based on current flow modeling and selected to avoid potential confounding effects of generating negative polarity over function-irrelevant brain areas. The positioning of return electrode on the contralateral cheek has successfully been used

610   in previous WM studies (see [36–38,49], as well as in AM studies [27,39,40]), and has been highlighted
611   as a good choice for tDCS montages aiming to modulate other cognitive functions as well [45].

613   **Blinding.** In single blind experiments, to ensure blinding of the participant, the position of the
614   stimulator and/or monitoring display should be out of participant's sight. This is especially
615   important when using stimulators that have lights indicating when the unit is on and/or
616   delivering current. For double-blind designs (when both participant and experimenter are
617   unaware of the protocol which is administered), one should use the double-blind option, or
618   similar option that is available for a given device. If such option is not available, the good
619   practice is to have two-experimenter procedure. That is, one experimenter comes in only to run
620   the stimulation protocol, while the other experimenter who runs the participant through the
621   experiment, including the subsequent memory task and analyzes the data, leaves the room just
622   before and during the stimulation. By methodological standards, double-blind experiments are
623   preferred to the single-blind designs because they reduce the bias or the "experimenter"
624   effects. This is highly relevant when conducting clinical trials and/or using the interview-based
625   assessments of cognitive functions. However, blinding of the experimenter is less of an issue
626   when participants are highly motivated to maximize their performance (which is mostly the
627   case in memory assessment or cognitive enhancement in general), and when the task is
628   administrated as well as scored automatically (i.e., when experimenter has little to no
629   intervention in the assessment phase).

631   **Activity during tDCS.** Authors of tDCS papers rarely report on what were the participants doing
632   during stimulation. When the activity is not reported it is usually implied that the participants
633   were instructed to sit comfortably and relax. However, the absence of structured activity
634   represents source of the uncontrollable "noise" in the experiments. Namely, 20 minutes is
635   rather long time, so some participants may use the time to relax (with possibility to even fall
636   asleep) while others may focus on tDCS sensations or start ruminating or excessively thinking
637   about some tDCS unrelated topics. There is evidence to suggest that function-relevant but not
638   tiring activity performed during tDCS has the potential to promote tDCS effects [50]. For these
639   reasons, in our experiments, participants perform either practice trials of the memory tasks to
640   be used as outcome measures or similar memory tasks. Practice trials are good choice because
641   they engage the same neural networks as the target function but are easier and therefore not
642   frustrating or tiring for the participants. Besides that, performing practice trials during
643   stimulation is economical in a sense that it cuts down the testing time following tDCS, which
644   comes as a benefit especially when the study design includes multiple tasks to be completed
645   post-tDCS. However, the practice trials are usually much shorter than 20 minutes, thus
646   alternative activity needs to be presented too. For this purpose, we have used common
647   memory games [40], that keep the participants focused, help them pass the time and keep the
648   mind off the tDCS induced sensations and make them overall more comfortable in the testing
649   setting. A few things to keep in mind when choosing the memory task to be performed during
650   tDCS are that the task should not be difficult but also not boring (adaptive tasks set at 80%
651   success rate are good in this context); the task should not have the material that might
652   interfere with subsequent memory assessment (e.g., when assessing memory for faces and
653   words, one can use abstract images/shapes pairs). Another important issue is the duration of

654 the "habituation period" i.e., how long after the beginning of stimulation should participants
655 start to perform the "distraction activity". There are individual differences in the intensity of
656 the sensation and habituation times, but majority of participants will be ready to start the
657 activity after 3-5 minutes of stimulation.
658
659 **Cutaneous sensations.** Some participants may be more sensitive to cutaneous tDCS effects,
660 thus reporting elevated levels of discomfort, although this does not happen very often. It is
661 important to inform participants about potential sensations they might experience prior the
662 experiment. If someone is afraid of the procedure, we often let participants "feel" the current
663 on their hand before putting the sponges on their head. The participants should be
664 continuously monitored and asked to provide feedback on their level of comfort and sensations
665 at regular intervals. If the participant reports increased level of discomfort, always offer to
666 abort the experiment. It is essential that the participants are aware that the stimulation can be
667 stopped at any time if they ask. If participant decides to stop the stimulation, the current
668 should be slowly turned down (abrupt cancelation of the stimulation protocol may induce even
669 stronger sensations). It is often recommended that in the case of unpleasant sensations the
670 current intensity is temporarily lowered to the highest comfortable level, until participant
671 adjusts, and then gradually returned to the target intensity. This seems like an appropriate
672 alternative to stopping the stimulation protocol, especially if tDCS is used in clinical setting.
673 However, when tDCS is used for the research purposes, and especially in relatively small
674 samples, it is essential that all participants undergo the same procedure. Therefore, stopping
675 the experiment is preferred to lowering the intensity of the stimulation for some participants
676 for some time.
677
678 **Reporting tDCS methodology and monitoring for potential confounds.** The tDCS research field
679 is highly heterogeneous regarding methods and measures, thus it is important to clearly report
680 all aspects of the tDCS procedure, including blinding procedure and assessment; the head-
681 positioning of the target as well as the position of the return electrode; the size and shape of
682 the electrodes; type of conducting substance used (saline or gel); the current intensity (mA) and
683 density (mA/cm^2) as well as the duration of fade-in/out period; the impedance levels if
684 measured; the duration of the stimulation (including the fade-in/out period); the detailed
685 account of the activities participants were engaged in during the stimulation; the timing and the
686 duration of the cognitive tasks following the stimulation (including break-times, if any). This
687 type of information facilitates standardization and systematic analysis of the published studies
688 (see recent review for example [51]). The aspects that are rarely reported on are the effect of
689 potentially moderating/confounding variables such as time of the day of tDCS session, level of
690 tiredness/mood reported by the participants, successfulness of blinding (i.e., beliefs about the
691 type of stimulation they are receiving), the order of experimental sessions in within-subject
692 designs, etc. Most of these variables have been reported to modulate the effects of tDCS, but
693 their effect remains understudied and inconsistently reported. Therefore, tDCS studies should
694 ensure to collect and report on any potentially confounding variables; for details on good
695 practices see **Tables 10A, 10B, 11** by Antal and colleagues [34].
696
697 Application of the described protocol for anodal tDCS either in its standard or, even more, in its

698 advanced form (i.e., oscillatory-modulated tDCS) provides a mean not only for enhancement of
699 memory functions (and prospective use in clinical populations), but also allows for investigation
700 of the neurobiology of the functional neural networks behind these functions.
701

708

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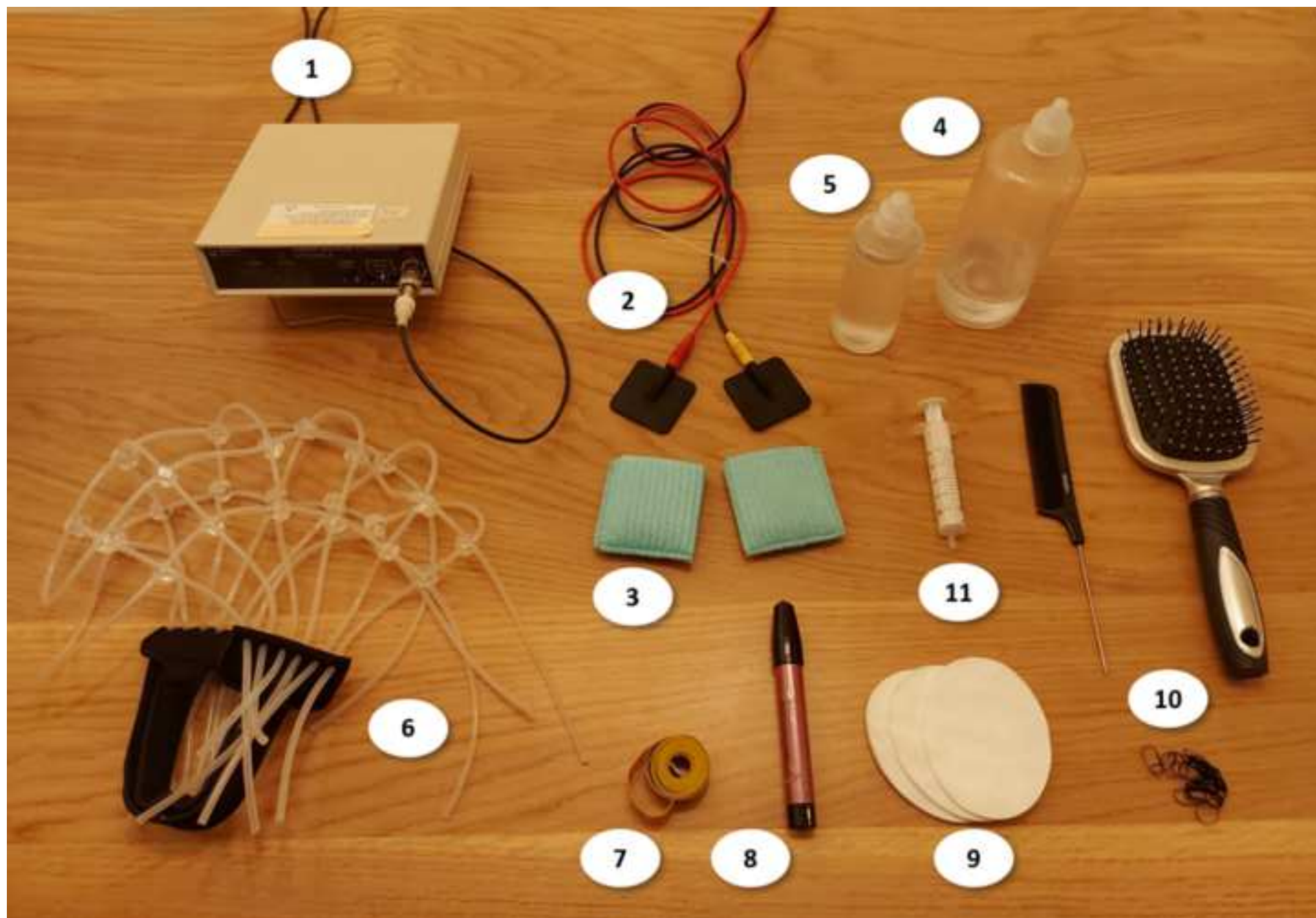
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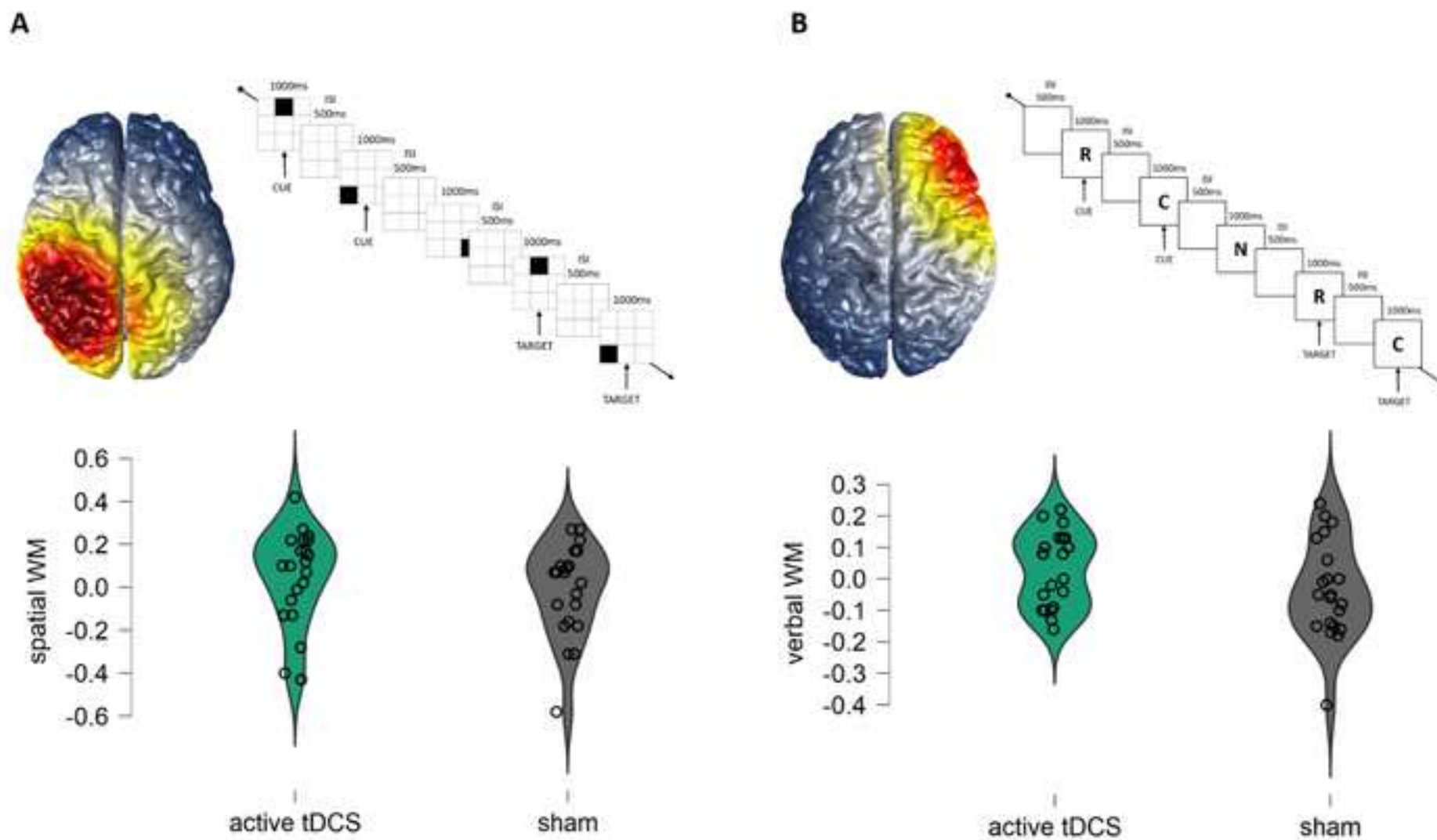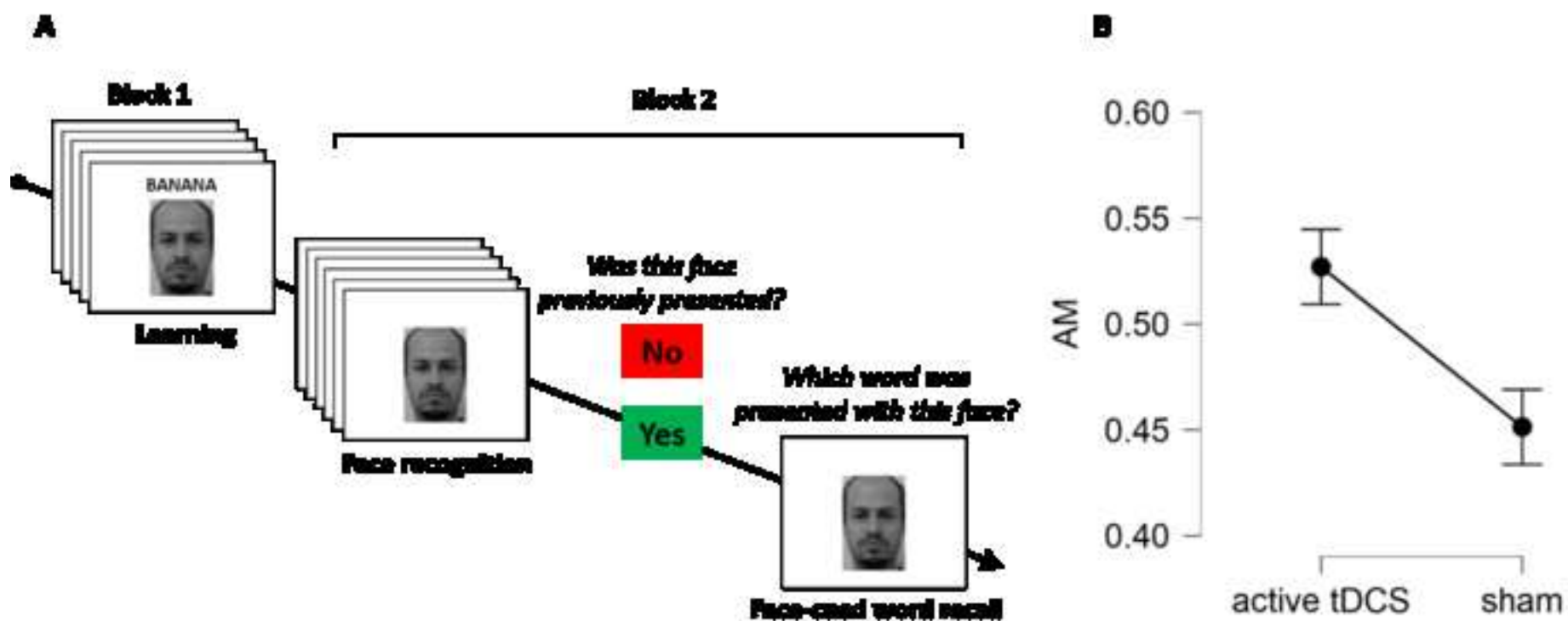839
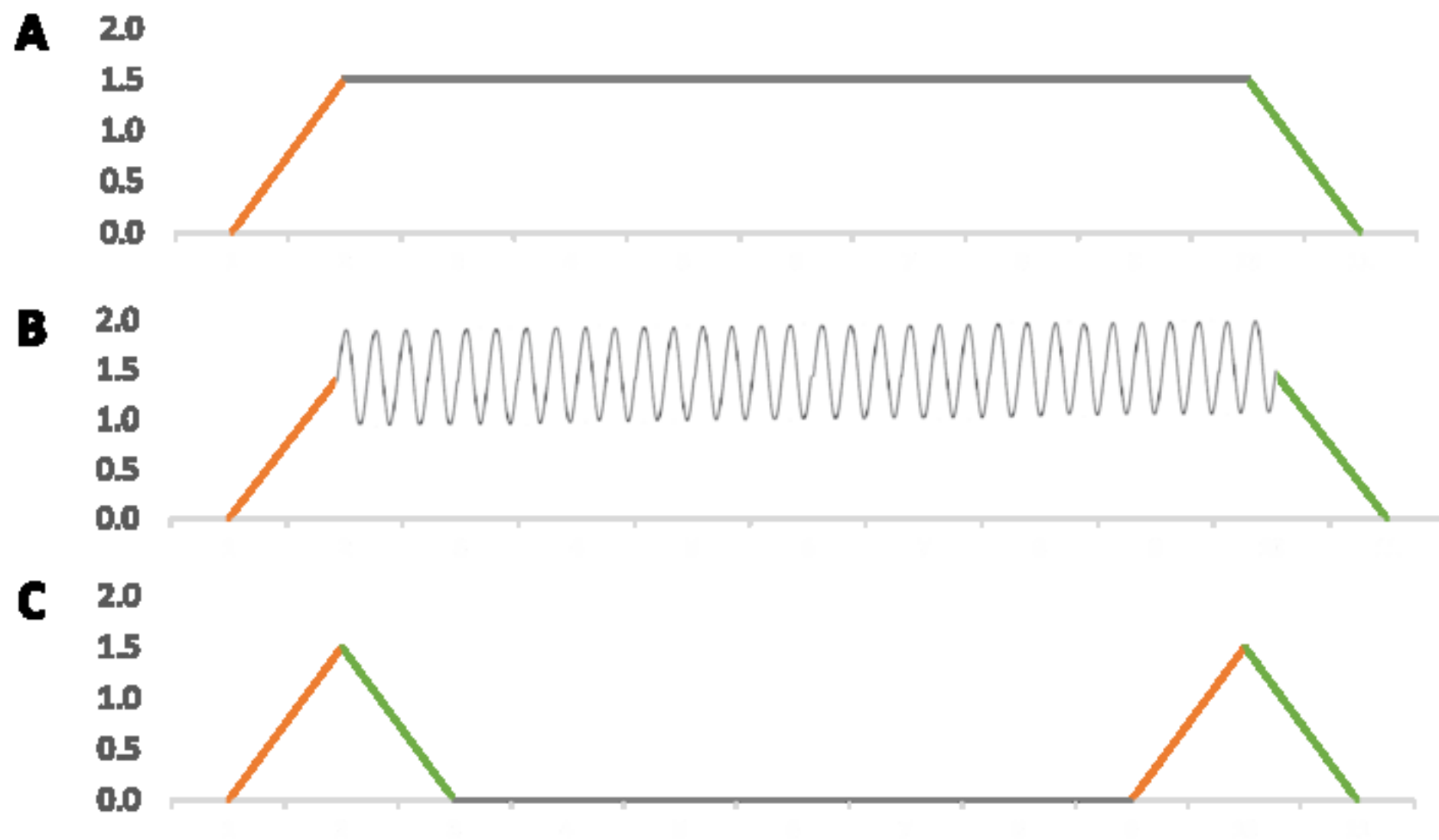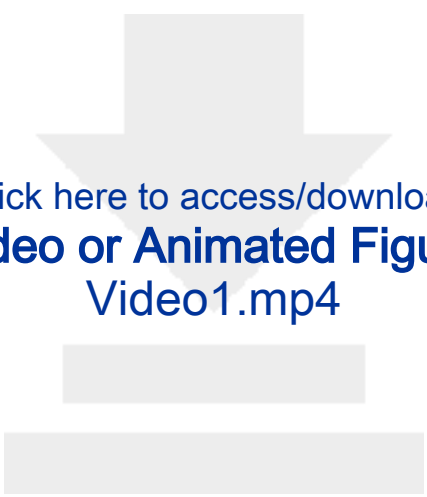
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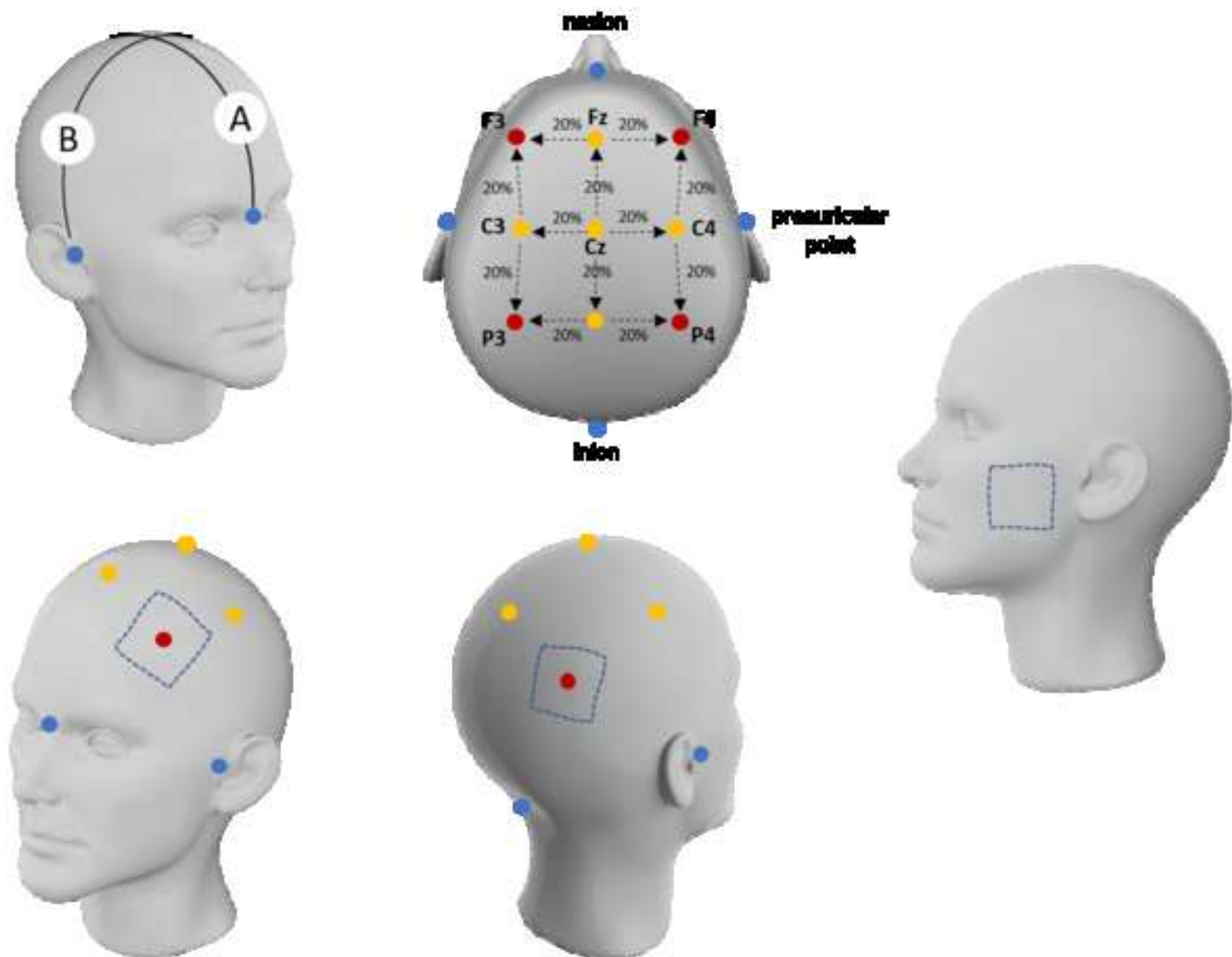
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Dear Editor and Production team,

We would like to thank you and both reviewers on valuable comments and suggestions, as well as overall positive feedback on our manuscript and video *Transcranial direct current stimulation (tDCS) for memory enhancement* (62681). We are now submitting the revised manuscript (all changes are marked in red font) and the point-by-point response to reviews and production team comments. The revised video is submitted via the link. We have addressed all concerns raised by reviewers, and we hope that the manuscript in its current form is suitable for publishing in JoVE.

Editorial and production comments	
Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues	Thank you – we have proofread the manuscript thoroughly.
For in-text formatting, corresponding reference numbers should appear as numbered superscripts after the appropriate statement(s).	In-text references are now formatted to be numbered superscripts, and we followed JoVe guidelines for end of text references as well.
Please do not use any footnotes.	Corrected – the two footnotes have been moved to the main text (L 85-89).
Please include an ethics statement before the numbered protocol steps, indicating that the protocol follows the guidelines of your institution's human research ethics committee.	Corrected - the ethics statement sentence has been added (L 386-389).
Please ensure that all text in the protocol section is written in the imperative tense as if telling someone how to do the technique (e.g., "Do this," "Ensure that," etc.). The actions should be described in the imperative tense in complete sentences wherever possible. Avoid usage of phrases such as "could be," "should be," and "would be" throughout the Protocol. Any text that cannot be written in the imperative tense may be added as a "Note." However, notes should be concise and used sparingly. Please include all safety procedures and use of hoods, etc.	Corrected – we checked and ensured that all text in the protocol section is written in imperative tense, with only a few exceptions (when the step is optional or could depend on the type of study design or equipment used). All the safety procedures have been covered in the protocol.
The Protocol should contain only action items that direct the reader to do something. Please move the discussion about the protocol to the Discussion.	Corrected – The protocol contains only action items - with a few words justifying or explain the rationale behind each step, or providing additional information about how the step should be performed e.g., *Write down the measures in Protocol sheet for each participant. These can be used to check against when taking measurements in subsequent sessions.*) These "additional information" is very short, and we believe add to the better understanding of how

	and why some steps should be performed, and do not require extensive discussion.
Please add more details to your protocol steps. Please ensure you answer the "how" question, i.e., how is the step performed?	We tried to add more details and ensure that the "how" question is covered throughout the protocol.
Step 1 of the protocol should be moved to the introduction.	We are aware that this may not be typical for JoVe papers. However, in this research field Study design is one of the most important aspects of the method, which is why we see it as the first steps of the protocol (please note that the Reviewers also complimented this part of the paper). Our main rationale behind having it in the Protocol rather than in the Introduction is that the decisions which are made in this regard are: a) methodological b) affect many of the steps to follow, c) we provide "how to" design a study and the rationale behind that. Therefore, we would highly appreciate if it is possible to leave this section as a part of the protocol.
Step 2 of the protocol can be moved to the Table of Materials. Please revise the table of the essential supplies, reagents, and equipment. The table should include the name, company, and catalog number of all relevant materials in separate columns in an xls/xlsx file. Please sort the Materials Table alphabetically by the name of the material.	As many different materials/devices/software's can be used to perform the described protocol – we believe that it is important to describe the properties/characteristics/utilities of the materials/devices and use generic terms of the products that are needed rather than providing names of manufacturers. We understand how catalogue numbers and manufacturers may be important for some protocols to ensure reproducibility of the results, However, in case of our protocol, many of the materials can be self-made (e.g., table with precalculated measures), or not strictly scientific items (e.g., comb, measuring tape, or a makeup product used to mark the skin), or even items that are very widely used (e.g., alcohol, syringe) thus many of the materials don't have "catalogue numbers". Furthermore, this paper is not industry-funded, thus we would like to avoid putting forward one manufacturer and omitting the names of others that are equal in terms of quality. This is why we give some examples in the text, but discuss how the same results can be achieved with different equipment/software.

Reviewer #1:	
Manuscript Summary: The protocol is very interested and well written. All the needed information is clearly presented. Major Concerns: No	Thank you for the positive feedback.
Minor Concerns: The authors could add a control frequency for the specificity of tACS. For instance gamma seems very important for aging.	Thank you for this suggestion – we have added this suggestion (L 151-154)
Reviewer #2:	
Manuscript Summary: The paper is excellent. The authors provide a detailed account of a tDCS protocol for memory enhancement that has proven its efficacy in multiple studies. The explanations are thorough. It will be a helpful resource for anyone looking to conduct a tDCS study about memory enhancement and who does not know where to start or does not know which tDCS protocol to use.	Thank you for taking the time to review our manuscript. We highly appreciate positive feedback any suggestions for improving the paper.
Major Concerns: Lines 392: I agree with the authors that letting the participant perform a task related to the variables studied is essential. However, this part could benefit from more explicit guidelines. Questions that are not answered but could matter: "How long should the habituation period to the tDCS stimulation last? After which duration of stimulation should the participant start to perform a task? What does the participant do during the first minutes of the stimulation?." Indeed, the authors did not discuss a habituation period. From my personal experience with using tDCS, I noticed that participants are often focused on the stimulation's sensations which hinders the completion of the task at hand if there is one. One option would be to only start the completion of the task after e.g. 5 minutes of stimulation (and during the habituation period, the researcher could do some small talk to put the participant at ease). In line with this, in many tDCS studies, there is usually a habituation period from 3 to 5 minutes.	Thank you for this comment – we have omitted to be specific regarding the habituation period and the timing of the tasks. We agree that this is an important point, and it seems that we all do it in the similar manner in our studies – however we fully agree it should be explicitly stated in the protocol. Following your suggestion, we have now added information to the protocol (L415 - 423), as well as to the discussion (L591-595)
Line 415: I was about to congratulate the authors for having included a link to computerized tasks, but when I followed the OSF link, I realized the tasks were removed from OSF in March. Are the authors planning on making them available again before publication? These tasks would be an essential addition to the paper and protocol. Additionally, I am also wondering which software the tasks were built with (e.g., only requiring	We are very sorry for this – out intention is to provide the tasks, but we were in the process of updating them during the submission of this manuscript. Now we made them available through OSF, and we hope they will be a useful resource for other researchers. All tasks are built in Open Sesame, so they are easy to adapt – we hope we will add the data on their psychometric

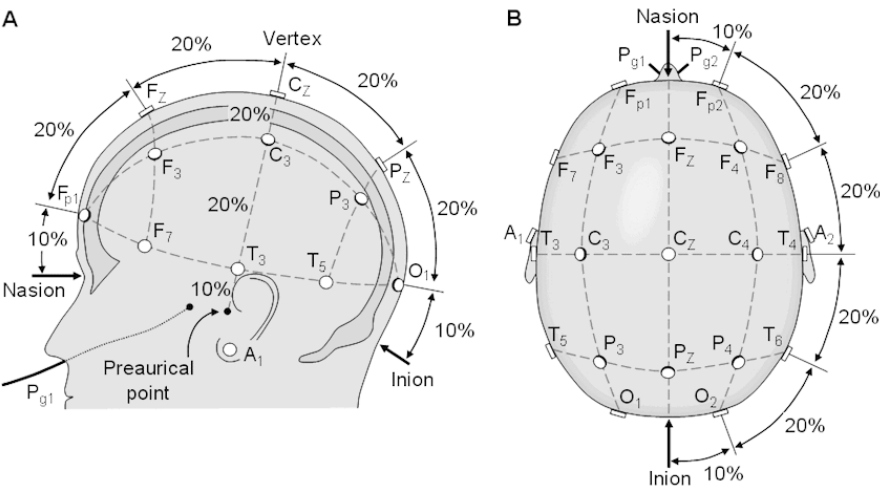|	
Open Sesame or a similar open-source and free software would make it easier for any researcher to use the tasks).	properties soon too.
Minor Concerns: Before the tDCS session: it would be worth summarizing the most common inclusion and especially exclusion criteria for tDCS studies. Additionally, the authors could provide or link to questionnaires including some or all of the following variables which could influence the effect of tDCS: substances use (nicotine, alcohol, caffeine/theine), the time of the day of the tDCS session, participants' handedness (this could be specified in the exclusion criteria), participants' medication use (this could be specified in the exclusion criteria), and the hormonal/menstrual cycle of female subjects. These variables are discussed in Antal et al. (2017), https://doi.org/10/gf9368. Perhaps the easiest option for the authors would be to refer the reader to tables 10A, 10B, and 11 in Antal et al. (2017). Moreover, the discussion or the protocol could benefit from mentioning the importance of clearly reporting the various parameters involved in a tDCS study, as it is an area in which tDCS papers are sometimes lacking. The authors could capitalize on recently published guidelines to report tDCS research (e.g., see the checklist provided in Hoebeke et al., 2021, https://doi.org/f83m).	Thank you for this suggestion, we have now added the list of most common inclusion/exclusion criteria in the Appendix. Thank you for suggesting this, we have now referred to the Antal et al. (2017) in both protocol and the discussion (L374-375; L614-631). Finally, we added the section in the discussion to highlight the importance of reporting tDCS parameters (we have listed them and we refer to the Hoebeke et al. (2021), as well as the effects of potential confounding variables (such as those listed in Antal et al. 2017) (L614-631).
On lines 361-362: It would be helpful to give an example of mood and alertness assessment.	Thank you for this suggestion we have now provided a reference to the questionnaire that is simple and works quite well (L384-385).
Reviewer #3	
Overview: This work describes experimental protocols that may be used to influence working memory (WM) as well as associative memory (WM). There is a lot to like about this manuscript. Given that an aim of this project is to standardize stimulation procedures, I think this work does a nice job of giving out essential background knowledge to inform best practices in experimental design. I particularly think the reasoning in section 1.4 Outcome measures is a particularly important point to impress upon the field. Overall, I think this work will make a good contribution to the tDCS literature, but have a few clarification points that the authors might consider.	Thank you for taking the time to review our paper - we highly appreciate positive feedback and useful suggestions on how to improve it.
Protocol: 1.1. Sham Control: For sham, some groups use a different sham procedure where very low	Thank you for this input – we have now added

constant stimulation (.1mA) is provided over the entire stimulation interval (For a brief Discussion, see Coffman, et al., 2014). The authors might mention this type of sham procedure as an alternative approach.	this type of sham procedure as an alternative under the section Sham tDCS (L311-314).
1.2. Within- or between-subjects design: This section suggests at least a 7 day delay between active versus sham stimulation in within-subjects design (which I agree is good practice), but it might be worth offering citation(s) that empirically supports this approach.	We design our studies with minimum of 7 days between the sessions, mainly to ensure no after-effects of tDCS (in one of our studies we have seen that the single session effects may persist up to 5 days). However, there are studies showing that even shorter wash-out periods do not affect the outcome, so we added those references as well. Unfortunately, we did not find any study that would provide a straightforward empirical support for "7 days" so we reframed it to "good practice". (L169 -171)
As an additional point, I'd suggest to offer guidance in this work about the duration of stimulation with respect to the AM/WM task. For example, if a researcher is interested in stimulation applied during both study/encoding and memory test in an AM task, then best practice is to ensure that stimulation cover both encoding and memory for all participants. This may mean that experimenters should use memory tasks that have precise timing, so that all participants undergo stimulation for the same segments of the task. This is yet another best practice to add precision to protocols.	We fully agree that precise timing is essential - we have now added the recommendation to use computerized tasks to control for the task duration and ensure precise timing. We have also added the recommendation on the duration of the task/task block, as well as the recommendation on the maximal duration of the cognitive assessment. (L211-227)
Again, I think this is a nice project that will promote more consistent procedures in the tDCS literature, which will benefit the field. References: Coffman, B. A., Clark, V. P., & Parasuraman, R. (2014). Battery powered thought: enhancement of attention, learning, and memory in healthy adults using transcranial direct current stimulation. Neuroimage, 85, 895-908	Thank you for providing us with useful suggestions.

Changes to be made by the Author(s) regarding the video	
Please increase the homogeneity between the video and the written manuscript. Please revise the narration to be more homogenous with the written manuscript. Ideally, the narration is a word for word reading of the written protocol.	Thank you for this comment. We have reviewed the consistency of the narration in the video with the written protocol.
Title Cards:	We have changed the title cards to have better

• Please add a high-quality chapter title cards. it looks low resolution compared to the video resolution. • Please capitalize the first letter of every important word in your chapter title cards. • 03:39 Please remove your Ethic title card from this place. This title card should appear between the end of the introduction and the beginning of the protocol."	resolution, and capitalized words. Ethics title card was moved as suggested.
Audio Editing and Pacing: Audio levels are quite low. Please ensure audio level peaks average around -9 dB.	Thank you for this comment – we have now increased the audio levels.

PARTICIPANT ID :	
STUDY ID:	

A /B	Cz	20%
31	15.5	6.2
32	16.0	6.4
33	16.5	6.6
34	17.0	6.8
35	17.5	7.0
36	18.0	7.2
37	18.5	7.4
38	19.0	7.6
39	19.5	7.8
40	20.0	8.0
41	20.5	8.2
42	21	8.4
43	21.5	8.6

Session 1	Session 2	Session 3	Session 4
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Notes:	Notes:	Notes:	Notes:

Appendix

Inclusion/exclusion criteria for tDCS study (suggested list for healthy participants study):

Native speakers or proficient language use (the language in which the study is conducted)
Normal or corrected to normal vision
Right-handed
Naïve to tDCS
Cognitive performance within the normal range

History of neurological/psychiatric disease; epilepsy /seizure
History of surgical procedure involving head or spinal cord
History of head trauma, followed by impairment of consciousness
Metal or electronic implants in the brain
Metal or electronic device in other sites of the body (cardiac pacemaker, traumatic metallic residual fragments)
Skin conditions (e.g. dermatitis, psoriasis, eczema) at the potential electrode placement sites; or highly sensitive skin
Fainting spells or syncope
Pregnancy
Use of medications (to be consulted with the medical doctor)
Experience of adverse effects following electric or magnetic stimulation