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Combining Behavior and EEG to Study the Effects of Mindfulness Meditation on Episodic Memory

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Aaron Berard, Ph.D.
Editor, *Journal of Visual Experiments*
1 Alewife Center Suite 200
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Dear Dr. Berard:

I am attaching a submission to the Journal of Visual Experiments entitled “Combining Behavior and EEG to Study the Effects of Mindfulness Meditation on Episodic Memory.” The manuscript is 12 pages long and includes 4 figures, plus another 2 tables.

My co-authors and I have no interests that might be interpreted as influencing this research. All APA ethical guidelines were followed in conducting this study, and all protocols received prior approval by the Bowdoin College Human Research Committee.

I will be serving as the corresponding author for this manuscript. All other authors have agreed to the byline order and to the submission of this manuscript in its current form. I have assumed responsibility for keeping my co-authors updated with regard to this paper’s progress through the editorial review process, the content of these reviews, and any revisions made. I understand that if this paper is accepted for publication, all co-authors will be required to sign a certification of authorship form.

Sincerely,

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TITLE:

Combining Behavior and EEG to Study the Effects of Mindfulness Meditation on Episodic Memory

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KEYWORDS:

Behavior, mindfulness meditation, episodic memory, memory retrieval, EEG, theta oscillations

SUMMARY:

Here we present a protocol for combining mindfulness meditation training, an episodic memory task, and EEG to understand the behavioral and neural effects of mindfulness meditation on episodic memory.

ABSTRACT:

Although there has been recent interest in how mindfulness meditation can affect episodic memory as well as brain structure and function, no study has examined the behavioral and neural effects of mindfulness meditation on episodic memory. Here we present a protocol that combines mindfulness meditation training, an episodic memory task, and EEG to examine how mindfulness meditation changes behavioral performance and the neural correlates of episodic memory. Subjects in a mindfulness meditation experimental group were compared to a waitlist control group. Subjects in the mindfulness meditation experimental group spent four weeks training and practicing mindfulness meditation. Mindfulness was measured before and after training using the Five Facet Mindfulness Questionnaire (FFMQ). Episodic memory was measured before and after training using a source recognition task. During the retrieval phase of the source recognition task, EEG was recorded. The results showed that mindfulness, source recognition behavioral performance, and EEG theta power in right frontal and left parietal channels increased following mindfulness meditation training. In addition, increases in mindfulness correlated with increases in theta power in right frontal channels. Therefore, results obtained from combining mindfulness meditation training, an episodic memory task, and EEG reveal the behavioral and neural effects of mindfulness meditation on episodic memory.

INTRODUCTION:

There has been recent interest in mindfulness meditation to treat symptoms of mental illness and to enhance cognition, but there is still much research to be done to understand the effects of mindfulness meditation on cognitive function. Previous research has shown that mindfulness meditation can reduce symptoms of stress, depression, generalized anxiety disorder, addictions, attention deficit disorder, and pain disorders¹⁻⁹, as well as increase attention and executive function^{2-7,10-16}.

Despite interest in the effects of mindfulness meditation on cognition, little research has been done on the effects of mindfulness meditation on episodic memory¹⁷. Given the contribution of attention and executive function to episodic encoding and retrieval, mindfulness meditation should also increase episodic memory. A few recent behavioral studies have shown that mindfulness training increases recognition memory recollection^{18,19} and free recall²⁰.

In addition to behavioral effects of mindfulness meditation on cognition, previous research has examined the effects of mindfulness meditation on the brain. Mindfulness meditation has been shown to change both the structure and function of the brain. Importantly, mindfulness meditation has been shown to change brain structure and function in networks related to episodic memory²¹⁻²³; specifically increasing grey matter volume and activity in the prefrontal cortex^{1,24-32} and hippocampus^{25,27,28,33-37} as well as increasing theta (4–8 Hz) power and coherence^{1,36,38-45}.

Therefore, previous research has separately examined the behavioral effects of mindfulness meditation on episodic memory¹⁷⁻²⁰ and the neural effects of mindfulness meditation^{1,21-45}. In order to understand the effects of mindfulness meditation on episodic memory and its neural correlates it is important to measure both behavior and brain activity during episodic memory. One method for studying the neural correlates of episodic memory is with electroencephalography (EEG). Here we describe a method for combining mindfulness meditation training with an episodic memory task while measuring EEG. By combining training in mindfulness meditation with behavioral and neural measures of episodic memory we can better understand the effects of mindfulness meditation on cognitive function.

PROTOCOL:

All procedures were approved by the Institutional Review Board of Bowdoin College, in accord with federal guidelines for the protection of human subjects.

1. Subject recruitment and preparation for the experiment

1.1 Recruit 40 18-29 year old subjects who are meditation naïve, right-handed, fluent English speakers, with normal or corrected to normal vision, with no neurological conditions.

NOTE: Studying younger children and older adults would require a separate age-specific study. The development of the frontal and parietal lobes is important for performing the episodic memory task. And there is variability in the EEG across age. Studying younger children and older adults requires age specific cognitive tasks and specialized EEG recording and data analysis

protocols that are not accommodated in the present protocol. Recruit only right-handed subjects to reduce variability in EEG activity.

1.2 Randomly assign 40 subjects to a mindfulness meditation experimental or waitlist control group for a total of 20 subjects in each group.

1.3 Schedule the experimental sessions and mindfulness meditation training such that the delay between pre-training and post-training experimental sessions are equal for the mindfulness meditation experimental and waitlist control groups (see **Figure 1** for a visual depiction of the sessions)

[Place **Figure 1** here]

1.4 Inform subjects about the procedures involved in the behavioral testing, the EEG recording, and the mindfulness meditation training. Ensure that subjects refrain from practicing meditation outside those conducted for the research study.

2. Mindfulness questionnaire

2.1 For each experimental session, have subjects complete the Five Facet Mindfulness Questionnaire (FFMQ)⁴⁶ (see **Supplementary File 1**).

2.2 Analyze the mindfulness data.

2.2.1 Measure each subject's mindfulness by calculating scores for FFMQ Total as well as Observe, Describe, Awareness, Nonjudge, and Nonreactive scales by summing up the scores for each subscale (note that for some items the scoring must be reversed (i.e., change 1 to 5, 2 to 4, 4 to 2, and 5 to 1) according to the instructions in the FFMQ⁴⁶ (see scoring instructions in **Supplementary File 1**).

2.2.2 Compare subjects' FFMQ Total as well as Observe, Describe, Awareness, Nonjudge, and Nonreactive scores for the mindfulness meditation experimental and waitlist control group across pre-training and post-training experimental sessions.

3. Episodic memory task

3.1 Prepare a list of 800 adjectives that are equated for word frequency according to the Kucera and Francis⁴⁷ word norms (see **Supplementary Files 3**).

3.2 For each experimental session, have subjects practice the encoding phase by presenting 10 words and performing the encoding task as described below.

3.3 For each experimental session, have subjects perform the encoding phase.

3.3.1 Have subjects study a list of 200 adjectives and either create a mental image of a spatial scene described by the adjective (place task) or think about the meaning of the word and rate its pleasantness (pleasant task).

3.3.2 After presentation of each word, ask subjects to rate how well they performed the encoding task (see **Figure 2** for a visual depiction of the encoding procedure).

3.4 For each experimental session, have subjects practice the source retrieval phase by presenting the 10 words that were shown at encoding practice and five new words, and perform the source retrieval task as described below.

3.5 For each experimental session, have subjects perform the source retrieval phase while recording EEG.

3.5.1 Present the 200 words that were shown at encoding randomly intermixed with 200 new words. Send time stamps that correspond to each behavioral condition to the EEG recording. Words should be presented in 20 blocks to give subjects rest breaks to rest their eyes.

3.5.2 During the presentation of each word, ask subjects to indicate if the word was new or if they recognized it as being studied in the encoding phase. For recognized words, ask subjects to indicate the source, whether the word was studied in the place task or the pleasant task (see **Figure 2** for a visual depiction of the source retrieval procedure).

[Place **Figure 2** here]

NOTE: The episodic memory task can be designed using any software designed for behavioral research such as EPrime which can send time stamps to the EEG recording using Task Events (see **Table of Materials**). Tutorials and example experiments are available online (e.g., <https://pstnet.com>, <https://step.talkbank.org>⁴⁸).

3.6 Mark each trial based on the behavioral condition and the subject's response (see **Figure 3** and **Figure 4**) and analyze the episodic memory behavioral data.

3.6.1 Measure subjects ability to remember the words by calculating item discrimination (item d' , see **Figure 3**):

$Z(\text{hit rate}) - Z(\text{false alarm rate})$

[Place **Figure 3** here]

3.6.2 Subjects ability to remember source information can be measured by calculating source discrimination (source d') (see **Figure 4**).

177 $Z(\text{correct source rate}) - Z(\text{incorrect source rate})$

178
179 [Place Figure 4 here]

180
181 3.6.3 Compare subjects' item and source discrimination (item and source d') for the mindfulness
182 meditation experimental and waitlist control group across pre-training and post-training
183 experimental sessions.

184 185 **4. EEG recording and analysis**

186 187 **4.1 Set up the EEG cap (see Table of Materials).**

188
189 NOTE: An EEG capping tutorial and other useful information is available through online resources
190 (e.g., <https://pursue.richmond.edu>⁴⁹).

191
192 4.1.1 Measure the subject's head and put all the electrodes on the correct size EEG cap according
193 to the extended international 10-20 system.

194
195 4.1.2 Clean the subject's forehead with an alcohol wipe.

196
197 4.1.3 Apply the EEG cap to the subject's head by parting their hair then inserting conductive gel
198 with a Luer-lock syringe with a blunted needle.

199
200 4.1.4 Using the EEG recording software, click on impedances and make sure they are under the
201 resistance level recommended by the specific EEG system chosen for use by the researchers.

202
203 4.1.5 Ask the subject to remain as still as possible during the experiment. Show the subject the
204 EEG signal when they are still and when they blink or make jaw or facial movement.

205 206 **4.2 Record the EEG.**

207
208 4.2.1 Set the EEG amplifier with the EEG recording software by clicking on edit workspace and
209 set to acquire signal with a .1–100 Hz bandpass filter and 500 Hz sampling rate for all subjects.

210 211 **4.2.2 Start the EEG recording.**

212
213 4.2.3 Start the source retrieval phase and ensure that the time stamps from the source retrieval
214 task are showing up in the EEG recording.

215
216 4.3 Once the subject has completed the source retrieval task, clean the EEG cap and electrodes
217 with deionized water and disinfectant.

218
219 4.4 Process and analyze the EEG data.

220

4.4.1 High-pass filter the data at 1 Hz and low-pass filter the data at 100 Hz.

4.4.2 Identify and interpolate bad channels using surrounding channels⁵⁰.

4.4.3 Re-reference the data to an average reference⁵¹.

4.4.4 Segment the data relative to the onset of each time stamp from the source retrieval task and subtract a pre-stimulus baseline period.

4.4.5 Identify and remove artifacts in the EEG data such as eye-blink and eye-movement artifacts. Detect and reject trials with large artifacts (voltage fluctuations of over 1,000 μ V or data 5 standard deviations beyond the norm). Reconstruct the EEG after running independent component analysis (ICA)⁵² and identifying and removing noise components⁵³.

4.4.6 Convert the EEG data to the time frequency domain across 100 log-spaced frequencies from 3 Hz to 125 Hz using a Morlet wavelet transformation with the wavelet increasing from 3 cycles at 3 Hz to 25 cycles at 125 Hz.

4.4.7 Compare theta power relative to pre-stimulus baseline in the mindfulness meditation experimental and waitlist control groups across pre-training and post-training experimental sessions in right frontal and left parietal channels which show effects during source retrieval⁵⁴⁻⁵⁷. All analyses should control for multiple comparisons.

NOTE: The EEG data can be processed and analyzed using publicly available software designed for signal processing such as EEGLab⁵⁸. EEGLab training workshops and tutorials are available through the Swartz Center for Computational Neuroscience (<https://scn.ucsd.edu/eeglab/index.php>).

5. Mindfulness meditation training

5.1 Hire a mindfulness meditation instructor trained in the Mindfulness Based Stress Reduction (MBSR) technique⁵⁹.

NOTE: Instructors trained in the MBSR technique can be found online (e.g. <https://www.brown.edu/public-health/mindfulness/programs/mbsr-teacher-recognition>).

5.2 Have the 20 subjects in the mindfulness meditation experimental group meet as a group for one hour each week for four weeks with the mindfulness meditation instructor.

NOTE: The standard MBSR course is eight weeks and includes breath awareness, sitting meditation, yoga, and relaxation techniques. The mindfulness meditation training should include aspects of the standard MBSR course such as breath awareness and sitting meditation (see **Supplementary File 2**). These practices, which relate to focusing attention and executive function are most likely to contribute to episodic memory.

5.3 Have subjects practice mindfulness meditation for at least 20 min each day using a guided breath awareness meditation recording provided by the mindfulness meditation instructor.

5.4 Track daily mindfulness meditation practice by asking subjects how many minutes they practiced mindfulness meditation, what they did during their meditation, and how the practice was going for them through daily emailed surveys (see **Table of Materials**).

NOTE: Researchers should consider excluding subjects who do not spend a substantial amount of time practicing mindfulness meditation.

5.5 Schedule the post-training experimental session as soon as possible after completion of the mindfulness meditation training.

NOTE: Researchers should consider excluding subjects who are unable to complete the post-training experimental session soon after the completion of the mindfulness meditation training. Please reach out to experts in cognitive neuroscience who use the EEG technique for randomized controlled experiments for further information.

REPRESENTATIVE RESULTS:

Representative results are reported for 40 meditation naïve, right-handed, fluent English-speaking subjects (10 male and 10 female subjects ranging from 18 to 22 years old in the mindfulness meditation experimental group and 7 male and 13 female subjects ranging from 18 to 22 years old in the waitlist control group). Behavioral and EEG data were analyzed using mixed analysis of variance (ANOVA) comparing mindfulness meditation experimental and waitlist control groups (experimental, control) across time (pre-training, post-training). All post-hoc tests corrected for multiple comparisons.

Mindfulness questionnaires

First, analysis assessed whether the mindfulness meditation training was successful. Subjects spent a substantial amount of time practicing mindfulness meditation and their mindfulness increased as measured by the FFMQ. Specifically, there was an interaction between group and time for FFMQ Total ($F(1,38) = 11.15$, $MSE = 67.67$, $p < .01$) and a marginal interaction between group and time for FFMQ Describe ($F(1,38) = 3.35$, $MSE = 12.26$, $p = .08$) and Nonjudge ($F(1,38) = 3.87$, $MSE = 15.37$, $p = .06$) scales. Scores increased from pre-training to post-training for FFMQ Total ($F(1,19) = 15.60$, $MSE = 63.34$, $p < .01$), Describe ($F(1,19) = 6.36$, $MSE = 8.44$, $p = .02$), and Nonjudge ($F(1,19) = 10.12$, $MSE = 8.60$, $p < .01$) scales for the mindfulness meditation experimental group, whereas the waitlist control group did not change (see **Table 1**).

[Place **Table 1** here].

Episodic memory

Second, analysis examined the effect of mindfulness meditation on behavioral performance of the episodic memory task. The mindfulness meditation training led to increases in source

memory as measured by source discrimination (source d'). Although there was no interaction between group and time ($F(1,38) = 1.16$, $MSE = .12$, $p = .29$), pairwise comparisons showed that source discrimination increased from pre-training to post-training for the mindfulness meditation experimental group ($F(1,19)=10.53$, $MSE=.12$, $p<.01$), but not the waitlist control group (see **Table 2**).

[Place **Table 2** here]

EEG Results

Third, EEG analysis examined the effect of mindfulness meditation on a neural correlate of episodic memory. Specifically, theta power was examined in right frontal and left parietal channels from 1000 to 1500 ms as these effects have been found in multiple source retrieval tasks⁵⁴⁻⁵⁷. For the left parietal channels, group interacted with time ($F(1,37) = 9.52$, $MSE = .92$, $p < .01$). Theta power increased from pre-training to post-training for the mindfulness meditation experimental group ($F(1,19) = 17.37$, $MSE = .23$, $p < .01$), but not the waitlist control group (see **Figure 5**).

[Place **Figure 5** here]

Finally, the correlation between changes in mindfulness and changes in episodic memory behavioral performance and EEG was examined in the mindfulness meditation experimental group. There was a positive correlation between increases in FFMQ Describe scores from pre-training to post-training and EEG theta power increases from pre-training to post-training in right frontal channels ($r = .72$, $n = 20$, $p < .01$, two-tailed, Bonferroni corrected; see **Figure 6**).

[Place **Figure 6** here]

FIGURE AND TABLE LEGENDS:

Figure 1: Visual depiction of the sessions. Subjects completed the Five Facet Mindfulness Questionnaire (FFMQ)⁴⁶ and performed the episodic memory task while EEG was recorded during the pre-training and post-training experimental sessions. Subjects were randomly assigned to either train in mindfulness meditation for four weeks or remain on a waitlist to be trained in mindfulness meditation.

Figure 2: Visual depiction of the experimental paradigm. During the episodic memory task, subjects studied adjectives and either imagined a scene (place task) or judged its pleasantness (pleasant task). During the source retrieval phase subjects decided which task was performed with each word ("Old Place Task" or "Old Pleasant Task") or "New". This figure has been modified from Nyhus et al.⁶⁰.

Figure 3: Data categories included in the measurement of word memory. Trials were marked based on the behavioral condition and the subject's response and used to calculate item discrimination (item d').

Figure 4: Data categories included in the measurement of source memory. Trials were marked based on the behavioral condition and the subject's response and used to calculate source discrimination (source d').

Figure 5: Effect of mindfulness meditation on theta power. Theta power for the mindfulness meditation experimental and the waitlist control group for the pre-training compared to the post-training experimental session. (A) Time-frequency spectrograms across times and frequencies in a right frontal channel. (B) Time-frequency spectrograms across times and frequencies in a left parietal channel. (C) Theta power across all channels from 1000–1500 ms and differences from pre-training to post-training. (C) Black * marks analyzed channels in right frontal and left parietal regions. Color scale: decibel change from pre-stimulus baseline and p -value of pre-training to post-training differences. This figure has been modified from Nyhus et al.⁶⁰.

Figure 6: Correlation between changes in FFMQ and theta power. Correlation between the average difference in theta power between pre-training and post-training for hits and correct rejections in right frontal channels and the difference in FFMQ Describe scores between pre-training and post-training. This figure has been modified from Nyhus et al.⁶⁰.

Table 1: Five Facet Mindfulness Questionnaire data. FFMQ Total as well as Observe, Describe, Awareness, Nonjudge, and Nonreactive scores for the mindfulness meditation experimental and the waitlist control group for the pre-training compared to the post-training experimental session. Means with standard errors in parentheses are shown. This table has been modified from Nyhus et al.⁶⁰.

Table 2: Source behavioral data. Hit rate, false alarm rate, source discrimination (source d') and response bias (source c) for the mindfulness meditation experimental and the waitlist control group for the pre-training compared to the post-training experimental session. Data are presented as means with standard errors in parentheses. This table has been modified from Nyhus et al.⁶⁰.

DISCUSSION:

The current protocol provided the first evidence that mindfulness meditation can increase source memory and theta oscillations. By combining training in mindfulness meditation with behavioral and neural measures we are better able to understand the effects of mindfulness meditation on episodic memory and its neural correlates.

Although previous research has separately examined the behavioral effects of mindfulness meditation on episodic memory¹⁷⁻²⁰ and the neural effects of mindfulness meditation^{1,21-45}, no study has combined behavior and EEG during episodic memory. In addition, previous research on mindfulness meditation has often studied expert meditators^{1,17,21-30,32,33,35-41,43,44} and therefore risks self-selection bias. By using a longitudinal design with randomly assigned mindfulness meditation and waitlist control groups we were better able to control for group

differences. Finally, previous research on mindfulness meditation has often used the full 8-week MBSR course, but the current study showed significant effects with only 4-weeks of mindfulness meditation training.

There were a number of key steps in successfully implementing these methods. First, random assignment to the mindfulness meditation experimental or waitlist control group was critical for ensuring that the groups were roughly equal. Second, it was important to focus the mindfulness meditation training on aspects of the MBSR course that relate to focusing attention and executive function (e.g., breath awareness) as these are most likely to contribute to episodic memory. Third, it was important to have subjects spend a substantial amount of time practicing mindfulness meditation and to accurately report the time they spent meditating each day. Fourth, it was important to equate the time between pre-training and post-training experimental sessions between the mindfulness meditation experimental and waitlist control groups to control for timing and to schedule the post-training experimental session as soon as possible following the mindfulness meditation training so that the effects of mindfulness meditation training did not dissipate prior to testing. Fifth, it is likely that mindfulness meditation affects episodic memory by increasing attention and executive function. Therefore, it was important to use an episodic memory task that requires executive function such as source memory. Finally, it is important to obtain high quality EEG data that is free of artifacts.

Although there were advantages to this method over existing methods, a few limitations should be noted. The effect of mindfulness meditation on source memory was weak. This could have resulted from using subjects who were healthy young adults with good memory performance or the limited amount of time that subjects spent practicing mindfulness meditation. The 4-week mindfulness meditation training was shorter than the standard 8-week MBSR course and, on average, subjects did not report spending the full 20 min practicing mindfulness meditation each day. In addition, there was no active control group, so it is unclear how mindfulness meditation compares to other treatments in boosting source memory or theta oscillations. Finally, the EEG analysis methods used here do not separate out the contribution of periodic oscillatory power from aperiodic 1/f non-oscillatory power which may affect the interpretation of the results. Therefore, future research should consider using subjects with weaker memory ability, implementing the full 8-week MBSR course, employing an active control condition, and using newly developed analysis methods that separate out oscillatory and 1/f non-oscillatory activity⁶¹.

Therefore, the current methods were successful in combining behavior and EEG to study the effects of mindfulness meditation on episodic memory. Future research should use these methods to compare mindfulness meditation with other treatments that have been shown to improve episodic memory and change the structure and function of the brain. In addition, future research should combine behavior and neural measures to examine the effect of mindfulness meditation on other facets of cognition. By combining behavioral and neural measures and comparing mindfulness meditation to alternative treatments we will be better able to determine the most promising treatments for cognitive enhancement.

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DISCLOSURES:

The authors have nothing to disclose.

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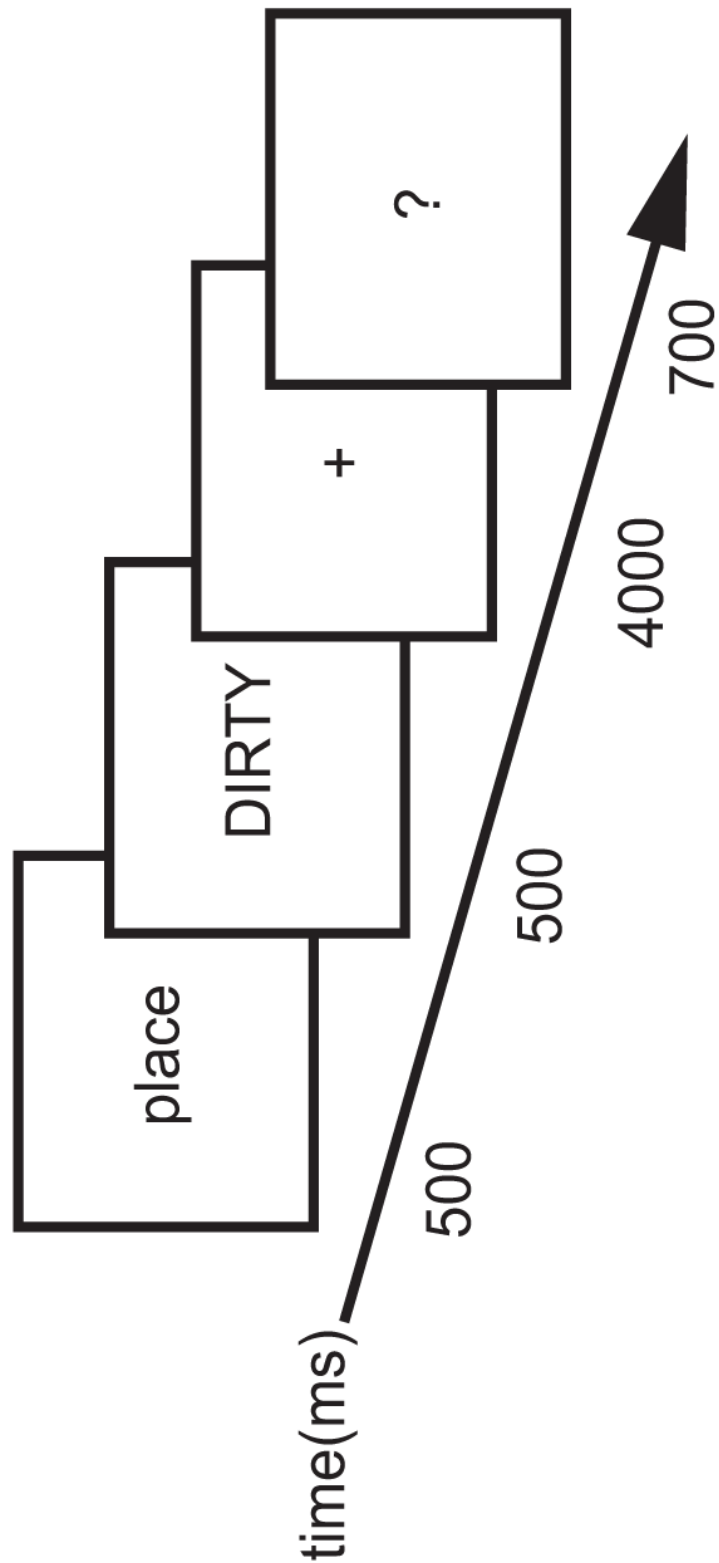
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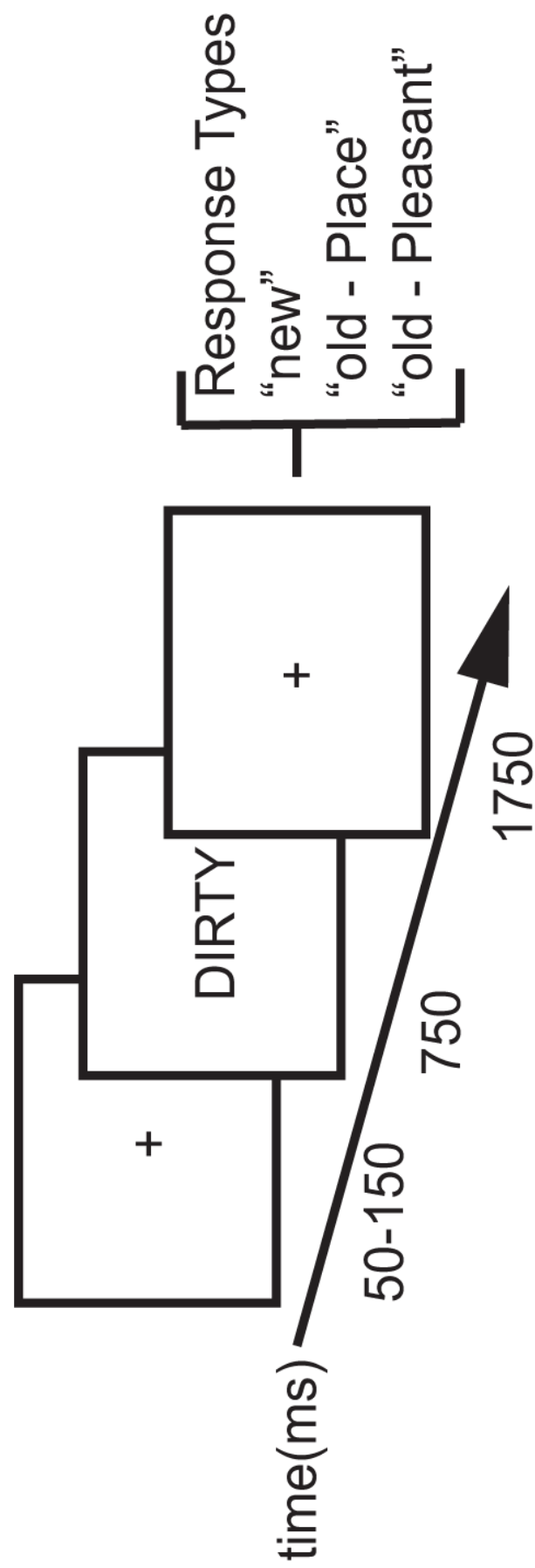
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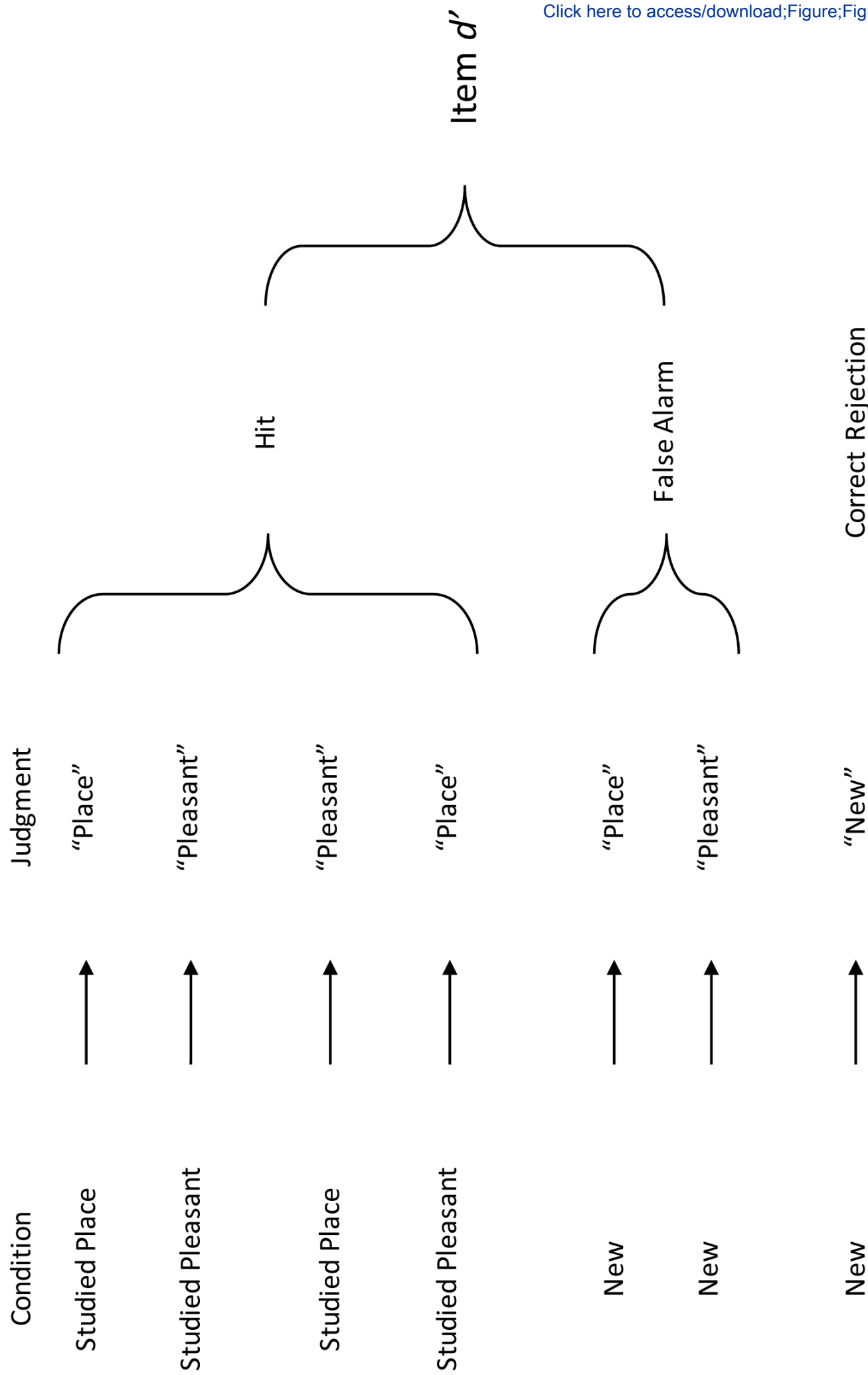


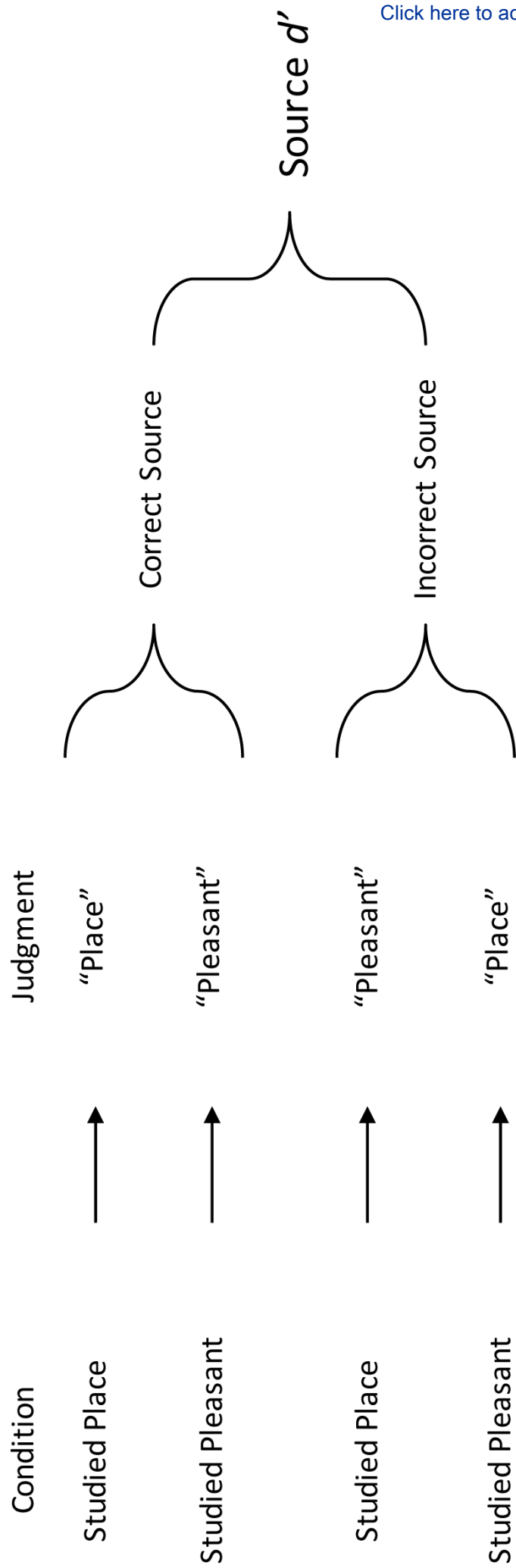
Encoding

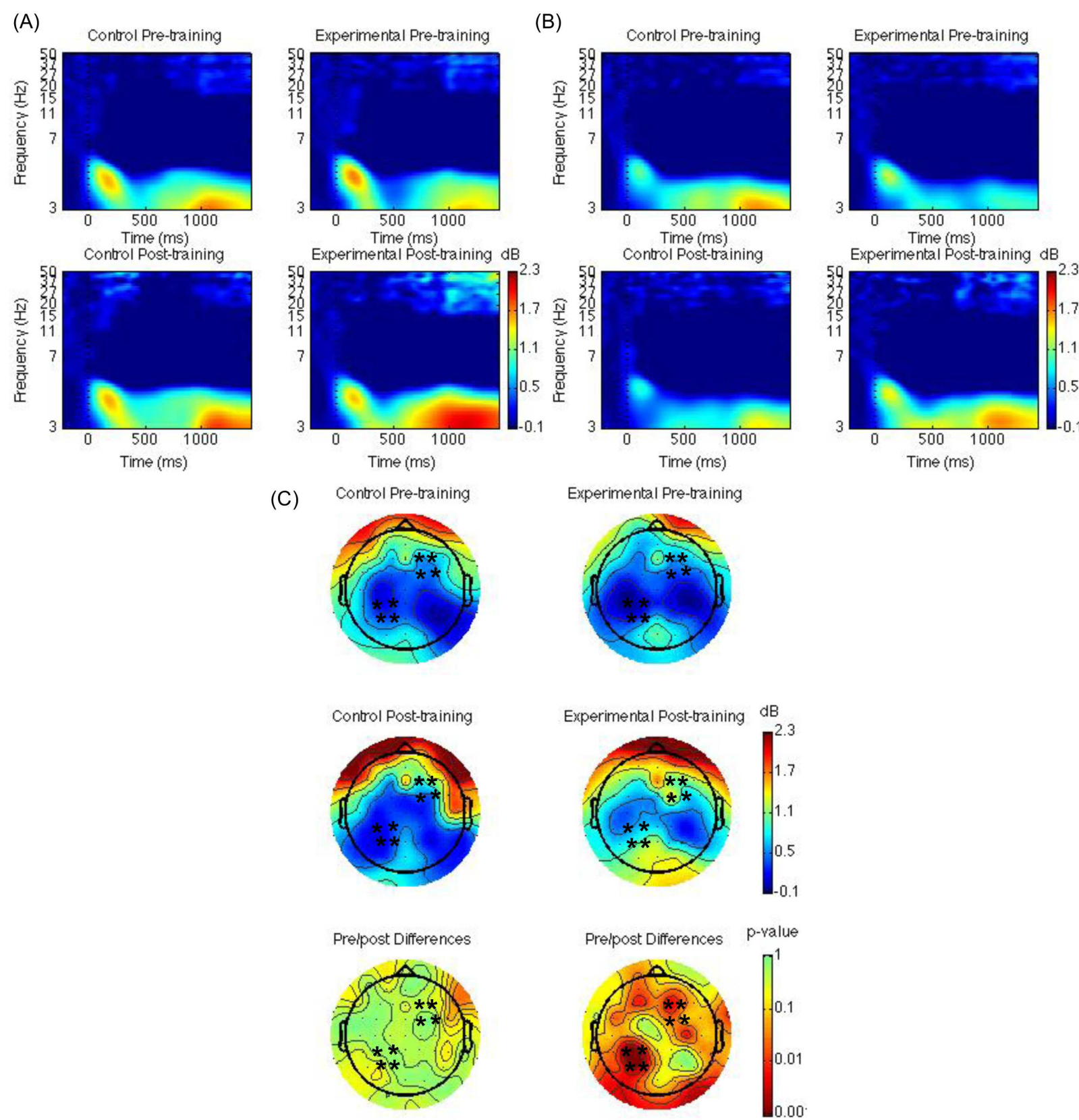


Source Retrieval

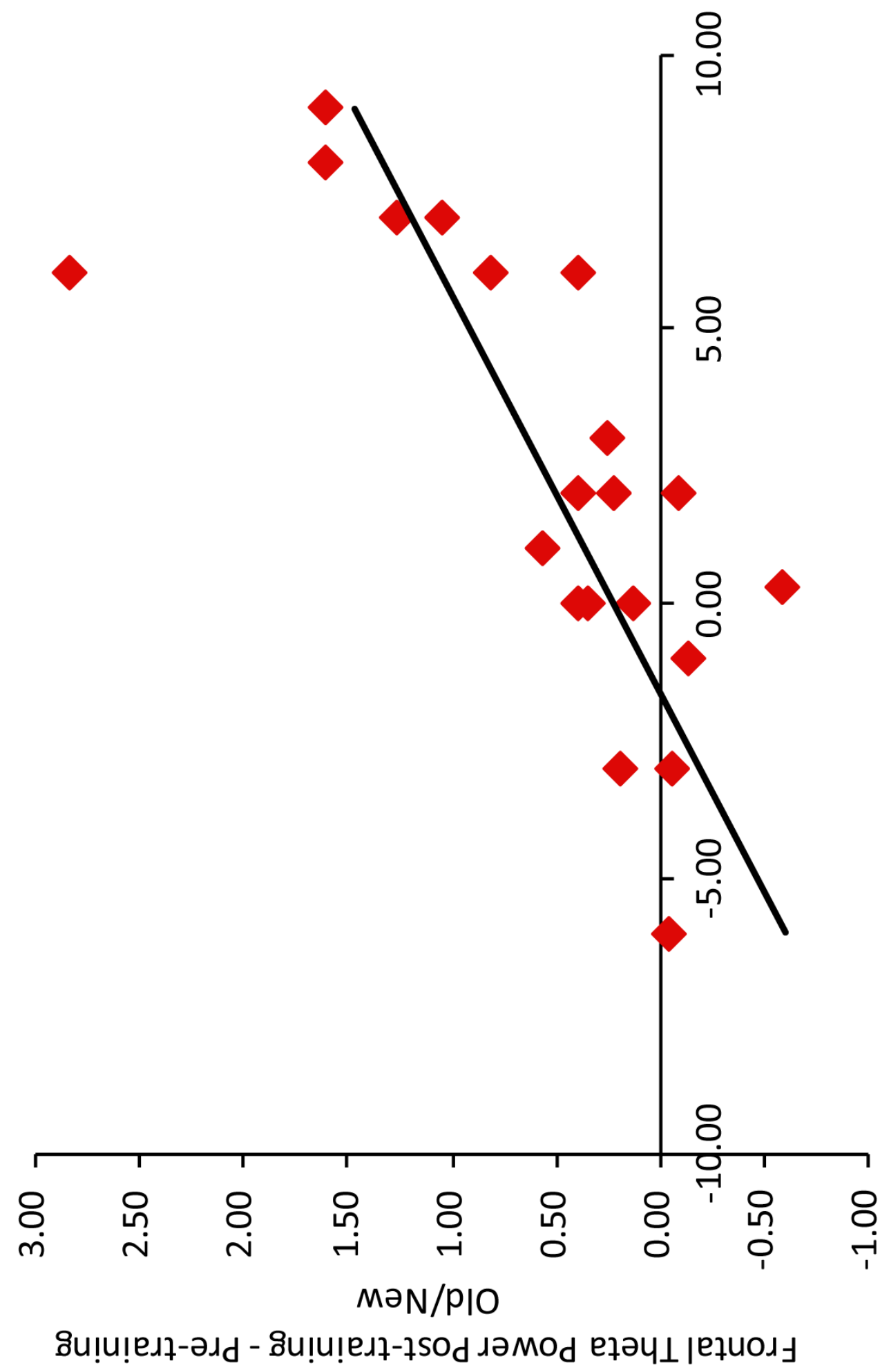








$R^2 = 0.51$



FFMQ Describe Post-training - Pre-training

	Experimental		Control	
	Pre-training	Post-training	Pre-training	Post-training
Total	128.13 (2.38)	138.07 (3.24)	123.59 (4.19)	121.25 (4.77)
Observe	26.98 (1.16)	28.70 (1.00)	23.83 (1.14)	23.70 (1.26)
Describe	29.5 (1.36)	31.82 (.99)	27.10 (1.25)	26.55 (1.26)
Awareness	25.25 (1.06)	26.95 (1.12)	25.27 (.94)	24.05 (1.28)
Nonjudge	24.65 (1.26)	27.60 (1.40)	27.50 (1.42)	27.00 (2.05)
Nonreactive	21.75 (.99)	23.00 (1.08)	19.90 (1.09)	19.95 (1.16)

		Experimental		Control	
Condition		Pre-training	Post-training	Pre-training	Post-training
Hit	Place correct soi	.66 (.02)	.67 (.03)	.71 (.03)	.69 (.02)
	Pleasantness coi	.61 (.03)	.72 (.03)	.64 (.05)	.74 (.03)
FA	Place incorrect s	.34 (.02)	.33 (.03)	.29 (.03)	.31 (.02)
	Pleasantness inc	.39 (.03)	.28 (.03)	.36 (.05)	.26 (.03)
Source <i>d'</i>		.70 (.11)	1.06 (.12)	1.04 (.17)	1.23 (.14)
Source <i>c</i>		-.06 (.05)	.07 (.05)	-.12 (.12)	.10 (.07)

Name of Material/ Equipment	Company	Catalog Number	Comments/Description
BrainVision actiCHamp	Brain Prodt	BP-09020	64-channel EEG system
BrainVision Recorder	Brain Prodt	BP-00020	EEG recording software for EEG data acquisition
E-Prime 2.0 Professional	Psychology	PST-100577	Software designed for behavioral research that can interface with th
Qualtrics	Qualtrics,	Core XM	Survey tool

ie EEG recording

March 25, 2020

Dear Dr. Cao,

I have attached a revision of my *Journal of Visualized Experiments* manuscript 61247, “Combining behavior and EEG to study the effects of mindfulness meditation on episodic memory”. I am very grateful to you and the reviewers for your constructive feedback on the previous draft of the manuscript, and I believe that the new version of the paper addresses the concerns that were raised during the previous round of reviews. Below, I first provide an overview of the editor and reviewers’ concerns and my response to these concerns. Then, I provide point-by-point responses to each of the editor and reviewers’ comments. Please do not hesitate to contact me by email (enyhus@bowdoin.edu) if you have any questions.

Sincerely,

Erika Nyhus

OVERVIEW OF CHANGES

The reviewers' main concerns were as follows:

Although the reviewers acknowledged that the paper clearly summarizes the methods, the general interest in the effect of mindfulness meditation in cognitive neuroscience, and the relevance of the paper to the journal, the editor and one of the reviewers noted lack of sufficient detail in the protocol.

As stated for the editor point # 4 and Reviewer 1 point # 1 we have added more details to the protocol.

POINT-BY-POINT REPLIES

Editor

POINT #1: Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues. The JoVEeditor will not copy-edit your manuscript and any errors in the submitted revision may be present in the published version.

RESPONSE: We have proofread and made corrections throughout the manuscript.

POINT #2: Please obtain explicit copyright permission to reuse any figures from a previous publication. Explicit permission can be expressed in the form of a letter from the editor or a link to the editorial policy that allows re-prints. Please upload this information as a .doc or .docx file to your Editorial Manager account. The Figure must

be cited appropriately in the Figure Legend, i.e. “This figure has been modified from [citation].”

RESPONSE: We have obtained copyrights permissions for each figure. Please see attached the permissions information from Frontiers in Human Neuroscience. The figures were reprinted from our previous work and were covered by Creative Commons permissions.

POINT #3: Please revise lines 33-35, 251-252, 259-263, 271-275, and 282-284 to avoid textual overlap with previously published work.

RESPONSE: Where possible we have revised the lines to avoid overlap with previously published work, but it was unclear to us how to revise the representative results.

POINT #4: Please add more details to your protocol steps. There should be enough detail in each step to supplement the actions seen in the video so that viewers can easily replicate the protocol. Please ensure you answer the “how” question, i.e., how is the step performed? Alternatively, add references to published material specifying how to perform the protocol action. See examples below.

RESPONSE: We have added more details to the protocol.

POINT #5: 2.2.1: Please describe how to calculate scores.

RESPONSE: We have added the following to the Mindfulness questionnaire section to describe how to score the FFMQ, “Subject’s mindfulness can be measured by calculating scores for FFMQ Total as well as Observe, Describe, Awareness, Nonjudge, and Nonreactive scales by summing up the scores for each subscale (note that for some items the scoring must be reversed (i.e. change 1 to 5, 2 to 4, 4 to 2, and 5 to 1) according to the instructions in the FFMQ⁴⁶ (see scoring instructions in Supplementary Files).”

POINT #6: 3.1: Please provide the list of adjectives used here. This can be provided in the supplemental file.

RESPONSE: We have uploaded the list of adjectives to the Supplementary Files.

POINT #7: 3.2: Please describe how to practice the source recognition task.

RESPONSE: We have added the following to the Episodic memory task section to describe how subjects practice the source encoding and retrieval phases, “For each experimental session, have subjects practice the encoding phase by presenting 10 words and performing the encoding task as described below...For each experimental session, have subjects practice the source retrieval phase by presenting the 10 words that were shown at encoding practice and five new word and performing the source retrieval task as described below.”

POINT #8: 3.2-3.4: When are these tasks performed? The timeline is unclear.

RESPONSE: The episodic memory task, including the source encoding phase and source retrieval phase, are performed during the pre-training and post-training experimental sessions. To clarify that the encoding and retrieval tasks are part of the episodic memory task, we have changed to encoding and retrieval “phase”.

POINT #9: Section 4: When is the EEG recording done? The timeline is unclear. It is not included in Figure 1.

RESPONSE: The EEG recording is done during the retrieval phase of the episodic memory task during the pre-training and post-training experimental sessions. To clarify when EEG recording is done we added the following to the Episodic memory task section, “For each experimental session, have subjects perform the source retrieval phase while recording EEG.” In addition, we have added EEG recording to Figure 1 to indicate when EEG recording is done.

POINT #10: 4.1.1: What are the proper locations? Please specify.

RESPONSE: Electrodes should be placed according to the 10-20 system. To clarify that the electrodes should be placed according to the 10-20 system we added the following to the EEG recording and analysis section, “Measure the subject’s head and put all the electrodes on the correct size EEG cap according to the extended international 10-20 system.”

POINT #11: 4.2.1: What are the trial markers?

RESPONSE: The trial markers are time stamps in the EEG corresponding to each behavioral condition. To clarify that the trial markers are time stamps in the EEG corresponding to each behavioral condition we added the following to the Episodic memory task section, “Send time stamps that correspond to each behavioral condition to the EEG recording...NOTE: The episodic memory task can be designed using any software designed for behavioral research such as EPrime which can send time stamps to the EEG recording using Task Events (see Materials).”

POINT #12: 5.2: How many subjects are included in one group?

RESPONSE: There should be 20 subjects in each group. To clarify the number of subjects we added the following to the Subject recruitment and preparation for the experiment section, “Randomly assign 40 subjects to a mindfulness meditation experimental or waitlist control group for a total of 20 subjects in each group.”

POINT #13: References: Please do not abbreviate journal titles; use full journal name.

RESPONSE: We have changed all journal titles to the full journal name.

Reviewer #1

POINT #1: The major concern regarding this manuscript concern the simplicity of the details. The protocol details are described in a simple, easy to follow format akin to a recipe. As an expert in the field who knows the intricate details of how to conduct randomized control trials combining human behavioral and electrophysiological data, I was able to read between the lines. The major issue is that there is much to read between the lines. The following are things that are described in simplistic ways, when in reality, there is much knowledge and experience that is needed to implement each one of these steps.

RESPONSE: As stated for the editor point # 4, we have added more details to the protocol.

POINT #2: Coding behavioral tasks in software such as E-prime

RESPONSE: We have added the following to the Episodic memory task section to direct readers to EPrime training, “EPrime tutorials and example experiments are available through Psychology Software Tools Inc. (<https://pstnet.com>) and through other online resources (e.g. <https://step.talkbank.org>⁴⁸).”

POINT #3: Setting up the EEG cap

RESPONSE: We have added the following to the EEG recording and analysis section to direct readers to EEG capping training, “An EEG capping tutorial and other useful information is available through online resources (e.g. <https://pursue.richmond.edu>⁴⁹).”

POINT #4: Creating time stamps that correspond to behavioral events and line up with the EEG data at the appropriate time

RESPONSE: As stated for the editor point # 11, we have clarified that the trial markers are time stamps in the EEG corresponding to each behavioral condition in the Episodic memory task section.

POINT #5: Hiring a mindfulness meditation expert

RESPONSE: We have added the following to the Mindfulness meditation training section to direct readers to MBSR certified instructors, “Instructors trained in the MBSR technique can be found online (e.g. <https://www.brown.edu/public-health/mindfulness/programs/mbsr-teacher-recognition>).”

POINT #6: Tracking the daily mindfulness meditation practice of all subjects

RESPONSE: We have added the following to the Mindfulness meditation training section to describe how to track daily mindfulness meditation, “Track daily mindfulness meditation practice by asking subjects how many minutes they practiced mindfulness

meditation, what they did during their meditation, and how the practice was going for them through daily emailed Qualtrics surveys (see Materials).”

POINT #7: Additionally, MATLAB and EEGLAB have steep learning curves. This protocol is excellent for experts in the field, but may not be possible for non-experts or scientists who do not have previous experience with these techniques.

RESPONSE: We have added the following to the EEG recording and analysis section to direct readers to EEGLab training “EEGLab training workshops and tutorials are available through the Swartz Center for Computational Neuroscience (<https://sccn.ucsd.edu/eeglab/index.php>).”

POINT #8: At minimum, there needs to be some acknowledgment that if you are to attempt this type of protocol, you should reach out to experts in the field of EEG data analysis and/or behavioral neuroscience who are familiar with running randomized clinical trials.

RESPONSE: In addition to the resources provided for EPrime training, EEG capping training, finding MBSR certified instructors, and EEGLab training, we have added the following to the end of the Protocol section, “NOTE: Please reach out to experts in Cognitive Neuroscience using the EEG technique for randomized controlled experiments for further information.”

POINT #9: The authors mention tracking daily mindfulness. What program will be used to do this? How will this be implemented? Participants left to their own devices over the course of 4 weeks generally do not adhere to study protocol. This program will be implemented more successfully if subjects are assigned a case manager, someone to follow them throughout the study and call them on a weekly basis.

RESPONSE: As stated for point # 6, we have added a description of how to track daily mindfulness meditation to the Mindfulness meditation training section. In addition, subjects in the mindfulness meditation experimental group meet as a group for one hour each week for four weeks with the mindfulness meditation instructor.

POINT #10: No sample size or participant demographics/characteristics reported. Please report.

RESPONSE: We have added the following to the beginning of the Representative Results section to describe the subjects, “Representative results are reported for 40 meditation naïve, right-handed, fluent English-speaking subjects (10 male and 10 female subjects ranging from 18-22 years old in the mindfulness meditation experimental group and 7 male and 13 female subjects ranging from 18-22 years old in the waitlist control group).”

POINT #11: Figure may be helpful to explain the different categories of responses in the episodic memory task-- hit, correct rejection, false alarm, correct source, incorrect source

RESPONSE: We have replaced the text with two figures to show the data categories included in the analysis (Figures 3 and 4).

POINT #12: Age range seems unnecessarily narrow; provide more detailed information

RESPONSE: We have added the following to the Subject recruitment and preparation for the experiment section to describe the age range, “Studying younger children and older adults would require a separate age-specific study. The development of the frontal and parietal lobes is important for performing the episodic memory task. And there is variability in the EEG across age. Studying younger children and older adults requires age specific cognitive tasks and specialized EEG recording and data analysis protocols that are not accommodated in the present protocol.”

POINT #13: 4 weeks is a short intervention and is not MBSR (which is 8 weeks and multidimensional including yoga, breathing, meditation and relaxation techniques). This should be clarified as to not misrepresent the teacher qualification and/or the integrity of MBSR.

RESPONSE: We have added the following to the Mindfulness meditation training section to clarify that the four weeks of mindfulness meditation training was not the standard MBSR course, “The standard MBSR course is eight weeks and includes breath awareness, sitting meditation, yoga, and relaxation techniques...These practices, which relate to focusing attention and executive function are most likely to contribute to episodic memory.” As stated for point # 5, we direct readers to MBSR certified instructors in the Mindfulness meditation training section.

Reviewer #3

POINT #1: The introduction is very well written. It's probably worth also citing the following two studies in the introductory background, which examined EEG activity related to recognition memory in long term meditators. In particular, the second study examined theta activity related to memory and did not find a difference between the meditation group and control group (it's also worth adjusting the point in the discussion that "no study has combined behaviour and EEG during episodic memory"):

Wang, M. Y., Freedman, G., Raj, K., Fitzgibbon, B. M., Sullivan, C., Tan, W. L., ... & Bailey, N. W. (2019). Mindfulness meditation alters neural activity underpinning working memory during tactile distraction. BioRxiv, 790584.

Bailey, N. W., Freedman, G., Raj, K., Spierings, K. N., Piccoli, L. R., Sullivan, C. M., ... & Fitzgerald, P. B. (2019). Mindfulness meditators show enhanced working memory performance concurrent with different brain region engagement patterns during recall. bioRxiv, 801746.

RESPONSE: We have added the citation to Wang et al., 2019 and Bailey et al., 2019 to the Introduction. But because these studies used working memory tasks we have not changed the discussion.

POINT #2: Point 2.2 - how would the mindfulness data be analysed? Is it important to note that some of the FFMQ items are reverse scored?

RESPONSE: As stated for the editor point # 5, we have added a description of how to score the FFMQ to the Mindfulness questionnaire section.

POINT #3: 3.1 - how would researchers equate for word frequency? (there's probably some research that could be referred to here right?). How many words should be in the list?

RESPONSE: As stated for the editor point # 6, we have uploaded the list of adjectives to the Supplementary Files which includes 800 adjectives that are equated for word frequency according to the Kucera and Francis⁴⁷ word norms

POINT #4: 3.3 and 3.4.1 - how long is each word presented for?

RESPONSE: The timeline of the experimental paradigm is shown in Figure 2. To clarify where to find the timing of the experimental paradigm we added the following to the Episodic memory task section, “see Figure 2 for a visual depiction of the encoding procedure...see Figure 2 for a visual depiction of the source retrieval procedure.”

POINT #5: I feel like 3.5 should be specified earlier, so that the researchers know that trials need to be marked with the proper condition prior to running the task (otherwise they won't be able to go back and perform this step if they missed it earlier). Also, "proper condition" could be better defined / more specifically explained, and it should probably be specified that the markers need to appear on the EEG trace.

RESPONSE: As stated for the editor point # 11 and Reviewer 1 point # 4, we have clarified that the trial markers are time stamps in the EEG corresponding to each behavioral condition in the Episodic memory task section. As stated for Reviewer 1 point # 11, we have replaced the text with two figures to show the data categories included in the analysis (Figures 3 and 4). To clarify that the proper condition is based on the behavioral condition and the subject's response we added the following to the Episodic memory task section, “Mark each trial based on the behavioral condition and the subject's response (see Figures 3 and 4) and analyze the episodic memory behavioral data.”

POINT #6: It's probably worth specifying the participant sessions early on in the methods, so researchers understand when they should schedule the sessions and how often the tasks / FFMQ is being recorded before they start reading about the details of what happens in each session.

RESPONSE: The sessions are shown in Figure 1. To clarify where to find the sessions we added the following to the Subject recruitment and preparation for the experiment section, “see Figure 1 for a visual depiction of the sessions.”

POINT #7: 4.1.1 - probably worth defining "proper locations" for the naïve researcher (eg. According to the 10-20 system, FPz located at a certain measurement from the nasion...).

RESPONSE: As stated for the editor point # 10, we have clarified that the electrodes should be placed according to the 10-20 system.

POINT #8: 4.1.4 - under 25kΩ might be different for different EEG systems. I would recommend something more like "under the resistance level recommended by the specific EEG recording system chosen for use by the researchers"

RESPONSE: We have changed to, “Using the EEG recording software (see Materials), click on impedances and make sure they are under the resistance level recommended by the specific EEG system chosen for use by the researchers.”

POINT #9: 4.2.2 - EEG recording software parameters should be set up before the source retrieval task is started and before the EEG is starting to record (and should be identical for all participants).

RESPONSE: The EEG recording parameters have been moved before EEG recording and the source retrieval phase in the EEG recording and analysis section. To clarify the EEG recording parameters we added the following to the EEG recording and analysis section, “Set the EEG amplifier with the EEG recording software by clicking on edit workspace and set to acquire signal with a .1-100 Hz bandpass filter and 500 Hz sampling rate for all subjects.”

POINT #10: 4.4.5 - It should be made more clear that the eye blinks are not being deleted, but that the data is being reconstructed after removal of the influence of eye blinks using ICA. It should be specified that the large artifacts are deleted epoch by epoch.

1.1.1 RESPONSE: We have added the following to the EEG recording and analysis section to clarify artifact rejection and correction, “Detect and reject trials with large artifacts (voltage fluctuations of over 1,000 μV or data 5 standard deviations beyond the norm). Reconstruct the EEG after running independent component analysis (ICA)⁵² and identifying and removing noise components⁵³.”

POINT #11: 4.4.6 - please specify the details of the Molet Wavelet transform (how many cycles, what resolution).

RESPONSE: We have added the following to the EEG recording and analysis section to describe the wavelet, “Convert the EEG data to the time frequency domain across 100

log-spaced frequencies from 3 Hz to 125 Hz using a Morlet wavelet transformation with the wavelet increasing from 3 cycles at 3 Hz to 25 cycles at 125 Hz.”

POINT #12: 4.4.7 - This sounds like a repeated measures ANOVA design, which cluster based statistics used with EEGLAB aren't recommended for. It might be worth recommending software that can perform this type of ANOVA design, or suggesting electrode locations that are likely to be good targets for analysis.

RESPONSE: We have added the following to the EEG recording and analysis section to suggest electrode locations for analysis, “Compare theta power relative to pre-stimulus baseline in the mindfulness meditation experimental and waitlist control groups across pre-training and post-training experimental sessions in right frontal and left parietal channels which show effects during source retrieval⁵⁴⁻⁵⁷.”

POINT #13: 5.5 - should there be an exclusion criteria for participants whose post-training experimental session is too long after successful completion? Similarly, for participants who practiced under a specified minimum amount?

RESPONSE: We did not have exclusion criteria for our experiment as it is not clear how long after completion of mindfulness meditation training is too long or what the minimum amount of practice is. We discuss the limited amount of time that subjects spent practicing mindfulness meditation in the Discussion. We have added the following to the Mindfulness meditation training section to suggest exclusion criteria for future research, “Researchers should consider excluding subjects who do not spend a substantial amount of time practicing mindfulness meditation... Researchers should consider excluding subjects who are unable to complete the post-training experimental session soon after the completion of the mindfulness meditation training.”

POINT #14: Episodic Memory results - p value is missing for the interaction between group and time.

RESPONSE: Thanks for the correction, we have added “ $p=.29$ ”.

POINT #15: I think it's probably worth noting the issue with 1/f activity confounding measurements of neural oscillations, and recommending future research address this issue (traditional EEG oscillation measurements do not separate neural oscillations from 1/f non-oscillatory activity, so when results are interpreted as reflecting differences in oscillations, this might be inaccurate). See Haller, M., Donoghue, T., Peterson, E., Varma, P., Sebastian, P., Gao, R., ... & Voytek, B. (2018). Parameterizing neural power spectra. BioRxiv, 299859 and Ouyang, G., Hildebrandt, A., Schmitz, F., & Herrmann, C. S. (2020). Decomposing alpha and 1/f brain activities reveals their differential associations with cognitive processing speed. NeuroImage, 205, 116304.

RESPONSE: We have added the following to the Discussion section to describe the issue with 1/f activity, “Finally, the EEG analysis methods used here do not separate out the contribution of periodic oscillatory power from aperiodic 1/f non-oscillatory power which

may affect the interpretation of the results. Therefore, future research should consider using subjects with weaker memory ability, implementing the full 8-week MBSR course, employing an active control condition, and using newly developed analysis methods that separate out oscillatory and 1/f non-oscillatory activity⁶¹.”

POINT #16: Is it also worth stating somewhere that multiple comparisons should be controlled for?

RESPONSE: Yes, multiple comparisons should be controlled for. To clarify that multiple comparisons should be controlled for we added the following to the EEG recording and analysis and the Representative results sections, “All analyses should control for multiple comparisons...All post-hoc tests corrected for multiple comparisons.”

Five Facet Mindfulness Questionnaire (FFMQ)

Ruth A. Baer, Ph.D.
University of Kentucky

Please rate each of the following statements using the scale provided. Write the number in the blank that best describes your own opinion of what is generally true for you.

1	2	3	4	5
never or very rarely true	rarely true	sometimes true	often true	very often or always true

- _____ 1. When I'm walking, I deliberately notice the sensations of my body moving.
- _____ 2. I'm good at finding words to describe my feelings.
- _____ 3. I criticize myself for having irrational or inappropriate emotions.
- _____ 4. I perceive my feelings and emotions without having to react to them.
- _____ 5. When I do things, my mind wanders off and I'm easily distracted.
- _____ 6. When I take a shower or bath, I stay alert to the sensations of water on my body.
- _____ 7. I can easily put my beliefs, opinions, and expectations into words.
- _____ 8. I don't pay attention to what I'm doing because I'm daydreaming, worrying, or otherwise distracted.
- _____ 9. I watch my feelings without getting lost in them.
- _____ 10. I tell myself I shouldn't be feeling the way I'm feeling.
- _____ 11. I notice how foods and drinks affect my thoughts, bodily sensations, and emotions.
- _____ 12. It's hard for me to find the words to describe what I'm thinking.
- _____ 13. I am easily distracted.
- _____ 14. I believe some of my thoughts are abnormal or bad and I shouldn't think that way.
- _____ 15. I pay attention to sensations, such as the wind in my hair or sun on my face.
- _____ 16. I have trouble thinking of the right words to express how I feel about things.
- _____ 17. I make judgments about whether my thoughts are good or bad.
- _____ 18. I find it difficult to stay focused on what's happening in the present.
- _____ 19. When I have distressing thoughts or images, I "step back" and am aware of the thought or image without getting taken over by it.
- _____ 20. I pay attention to sounds, such as clocks ticking, birds chirping, or cars passing.
- _____ 21. In difficult situations, I can pause without immediately reacting.

1	2	3	4	5
never or very rarely true	rarely true	sometimes true	often true	very often or always true

- _____ 22. When I have a sensation in my body, it's difficult for me to describe it because I can't find the right words.
- _____ 23. It seems I am "running on automatic" without much awareness of what I'm doing.
- _____ 24. When I have distressing thoughts or images, I feel calm soon after.
- _____ 25. I tell myself that I shouldn't be thinking the way I'm thinking.
- _____ 26. I notice the smells and aromas of things.
- _____ 27. Even when I'm feeling terribly upset, I can find a way to put it into words.
- _____ 28. I rush through activities without being really attentive to them.
- _____ 29. When I have distressing thoughts or images I am able just to notice them without reacting.
- _____ 30. I think some of my emotions are bad or inappropriate and I shouldn't feel them.
- _____ 31. I notice visual elements in art or nature, such as colors, shapes, textures, or patterns of light and shadow.
- _____ 32. My natural tendency is to put my experiences into words.
- _____ 33. When I have distressing thoughts or images, I just notice them and let them go.
- _____ 34. I do jobs or tasks automatically without being aware of what I'm doing.
- _____ 35. When I have distressing thoughts or images, I judge myself as good or bad, depending what the thought/image is about.
- _____ 36. I pay attention to how my emotions affect my thoughts and behavior.
- _____ 37. I can usually describe how I feel at the moment in considerable detail.
- _____ 38. I find myself doing things without paying attention.
- _____ 39. I disapprove of myself when I have irrational ideas.

FFMQ Scoring instructions

For all items marked “R” the scoring must be reversed. Change 1 to 5, 2 to 4, 4 to 2, and 5 to 1 (3 stays unchanged). Then sum the scores for each subscale.

Observing

1, 6, 11, 15, 20, 26, 31, 36

Describing

2, 7, 12R, 16R, 22R, 27, 32, 37

Acting with awareness

5R, 8R, 13R, 18R, 23R, 28R, 34R, 38R

Nonjudging of inner experience

3R, 10R, 14R, 17R, 25R, 30R, 35R, 39R

Nonreactivity to inner experience

4, 9, 19, 21, 24, 29, 33

Bowdoin Mindfulness Research Project: Class One Outline

6:00-6:10	Welcome and brief overview of program. 1-2 minute breathing space to transition from busyness of life to class. Introductions
6:10-6:15	Remind participants of guidelines: importance of attendance, within group confidentiality and limits of confidentiality, importance of taking care of one's self, refraining from offering advice, NOT reading about mindfulness for these 4 weeks, try not to wear perfume or other heavy scents to class, what to do if late or miss a session, how to contact teacher
6:15-6:35	Mindfulness attention exercise – Breath focus
6:35-6:50	Self Inquiry and questions <ul style="list-style-type: none">• What did you notice?• How is this different than you normally would pay attention?• How could this be of benefit to you?
6:50-6:55	Review invitation for home practice
6:55-7:00	Brief Breath Focus closing and thank you

Bowdoin Mindfulness Research Project: Class Two - Four Outline

6:00-6:05	1-2 minute breathing space to transition from busyness of life to class.
6:05-6:15	Review home practice
6:15-6:40	Mindfulness guided attention exercise – Breath focus
6:40-6:55	Self Inquiry and questions <ul style="list-style-type: none">• What did you notice?• How is this different than you normally would pay attention?• How could this be of benefit to you?
6:55-7:00	Review invitation for home practice Brief Breath Focus closing and thank you

Materials needed:

Cushions, blankets

Handouts

Contact Information, class schedule, homework summary, CD or link to download

Introductions

Try to steer introductions away from typical occupation, location info to present moment class-focused comments

Welcome all observations and normalize concerns

Bowdoin Mindfulness Research Project

Class One

Contact information:

Ben Tipton
bensimpleliving@gmail.com

Class Schedule:

Class One: XXXXX
Class Two: XXXXX
Class Three: XXXXX
Class Four: XXXXX

Class Guidelines:

- If you will be late or you must miss a class, please call or email me to let me know.
- Please maintain confidentiality outside of class. You may discuss your own experiences when talking with others, but please do not share any information about other participants.
- If possible, try not to wear perfume or other strong scents to class.
- Take care of yourself: if something doesn't feel right for your mind or body, ease off, and feel free to speak with me about any problems or questions that arise.

Home Practice:

- Use the provided recording to practice the breath focus meditation each day this week
- Bring mindful attention to one activity a day (e.g., brushing your teeth, washing your hands, sipping your coffee)

<u>StudyPrac</u>	<u>TestPrac</u>	<u>StudyBuffers</u>	<u>TestBuffers</u>
AVUNCULA	AVUNCULAR	DECEIVABL	TUBULAR
INCONTINE	INCONTINENT	DEFINABLE	DEVELOPABLE
KNIGHTED	KNIGHTED	FOURSQUA	WEARABLE
HINDER	HINDER	VEHICULAF	INDIGENT
APPEASABI	APPEASABLE		FORGIVABLE
LINEAR	LINEAR		OVULAR
BOOKABLE	BOOKABLE		MECHANICAL
CONFLUEN	CONFLUENT		MINOR
WHATEVER	WHATEVER		AURICULAR
FLUORESCI	FLUORESCENT		GLANDULAR
	IMPERTINENT		AZURE
	INSISTENT		UNDERSIGNED
	RECTANGULAR		DEXTER
	INEFFICIENT		SHEER
	STORABLE		SURE
			IMPRUDENT
			ALLIED
			MOLECULAR
			JAUNDICED
			SPECULAR
			SUPER
			LOGICAL
			INNER
			WHATSOE'ER
			KOSHER
			ANNULAR
			ESURIENT
			EITHER
			PRESERVABLE
			RECEIVABLE
			CORPUSCULAR
			COALESCENT
			RENASCENT
			LATTER
			ENTIRE
			PONTIFICAL
			CUTICULAR
			SKETCHABLE
			ALVEOLAR
			ANIMALCULAR
			ALTERABLE
			VERMICULAR
			PERISHABLE
			POLAR
			MATHEMATICAL
			RECORDABLE
			HOAR
			PAINTABLE
			TUMESCENT
			RELIEVABLE
			LOPPING
			DIRE
			AXILLAR
			INFERIOR

SORE
ELDER
ENLIGHTENING
PRIOR
PESTILENT
VELAR
OUR
DETESTABLE
PAPILLAR
RETICENT
AFIRE
SEMICIRCULAR
DRAMATIZABLE
ANTERIOR
LIKABLE
ARITHMETICAL
INSINCERE
EXCEEDING
EFFLUENT
SENTIENT
INTERCURRENT
CONCEIVABLE
HEARTSORE
IRREGULAR
ARTICULAR
REMINISCENT
APPLIABLE
THREADBARE
DISSIDENT
UTTER
UNFITTING
VENTRICULAR
IMMANENT
CHARGEABLE
THEOLOGICAL
TUTELAR
DOUR
CONSISTENT
CLASSIFIABLE
CLEANSABLE
OBEDIENT
DREAR
REMOVABLE
ABSTINENT
OBSERVABLE
BARNDOOR
VALVULAR
QUADRANGULAR
SLENDER
POOR
PERMUTABLE
OTHER
UNFAMILIAR
OUTER
WEAKENING

DEFERENT
LOVEABLE
DECUMBENT
TINTINNABULAR
INFLUENT
INTERDEPENDENT
INFLAMMABLE
INCIPIENT
CURVILINEAR
OCULAR
DIFFERENT
PENINSULAR
DAPPER
SCAPULAR
ENCYCLICAL
REGRETTABLE
CHANGEABLE
DRINKABLE
SINGULAR
INCONSEQUENT
COLLINEAR
SPARE
SUITABLE
PALMAR
VASCULAR
PHOSPHORESCENT
DESCRIBABLE
COGENT
CHEMICAL
SEVERABLE
ULTERIOR
PUTRESCENT
ROTATABLE
RECRUDESCENT
TUBERCULAR
ORACULAR
CONSULAR
CONVENIENT
PRINTABLE
CLAVICULAR
ACADEMICAL
DEBATABLE
FORMER
HYPOTHETICAL
APPROVABLE
EVANGELICAL
RATABLE
MAJOR
SIMILAR
INCONVENIENT
UNPOPULAR

<u>stim</u>	kffreq	nlet
SOLEMN	12	6
NOBLE	23	5
DISMAL	8	6
SATIRICAL	3	9
BROWN	176	5
BAD	142	3
DIDACTIC	0	8
DELICIOUS	4	9
FORENSIC	7	8
BLOODY	8	6
RENOWNED	2	8
SHINY	3	5
GEOMETRIC	17	9
BRIEF	73	5
RHYTHMIC	1	10
SIMPLE	161	6
SMALL	542	5
INDULGENT	2	9
FAIRY	4	5
ACCESSIBLE	5	10
NAZI	13	4
PERILOUS	8	8
FANATICAL	2	9
SQUEAMISH	1	9
FESTIVE	2	7
POETIC	31	6
METICULOUS	1	10
STUDIOUS	1	8
CAUTIONARY	0	10
TURKISH	12	7
SAMOAN	0	6
SAVAGE	22	6
CALM	35	4
BLESSED	13	7
VETERINARY	4	10
NICE	75	4
SWEATY	5	6
PLANETARY	21	9
CARIBBEAN	7	9
PERSIAN	10	7
NOXIOUS	2	7
BABYISH	0	7
FLOWERY	0	7
BOOKISH	1	7
COSMETIC	1	8
ARCH	13	4
BAROQUE	11	7
SUBTLE	25	6
FLASHY	3	6
GRISLY	2	6
CLASSY	0	6
SUSPICIOUS	13	10
VILE	5	4
MATURE	31	6
PARISIAN	3	8
UNDAMAGE	1	9

BUSY	58	4
GENEROUS	25	8
UNCLEAN	4	7
VIOLENT	33	7
CUBAN	19	5
BUFF	5	4
SHARP	72	5
HIGH	497	4
CONTENT	53	7
DISHONEST	2	9
COLOMBIAN	2	9
RARE	41	4
PUBLIC	438	6
FURIOUS	8	7
MURDEROL	4	9
KOREAN	11	6
BAY	57	3
WARM	67	4
PALE	58	4
ANGRY	45	5
SPOOKY	2	6
INTERIOR	74	8
DOGMATIC	4	8
HOMELY	9	6
GAUDY	7	5
MEDICAL	162	7
RAINY	5	5
RIGHTEOUS	5	9
AWKWARD	11	7
APATHETIC	1	9
HOSPITABL	4	10
SOCIAL	380	6
SERBIAN	0	7
SOAPY	2	5
TRIBAL	6	6
COMICAL	0	7
PHALLIC	0	7
SOMBRE	2	6
TRANQUIL	2	8
BLEAK	10	5
GRAPHIC	6	7
BIG	360	3
CRAZY	34	5
DETECTIVE	52	9
LAVISH	3	6
UNNATURAL	8	9
INDUSTRIAL	143	10
MYTHICAL	0	8
GALACTIC	1	8
MALODORC	0	10
PHENOMEN	2	10
ETHICAL	29	7
AFRAID	57	6
SEEDY	0	5
ABOMINABL	0	10
SACRED	38	6
VULGAR	7	6

SHABBY	5	6
ALIEN	16	5
DUMB	13	4
MUSICAL	85	7
NAKED	32	5
GRAY	80	4
DIM	19	3
EXTREME	62	7
FEARSOME	1	8
AGLOW	0	5
FLORAL	3	6
MEDITATIVE	2	10
MODEST	29	6
CAUTIOUS	10	8
ANXIOUS	29	7
FOGGY	5	5
FICTIONAL	13	9
LAZY	9	4
INCOMPLET	13	10
VALUABLE	45	8
IDLE	13	4
UNKEPT	0	6
STORMY	8	6
QUAINT	12	6
TACKY	0	5
UNSIGHTLY	1	9
EXPENSIVE	44	9
CREEPY	1	6
REBELLIOU	2	10
CRIMINAL	24	8
GAY	30	3
FISHY	0	5
TIRESOME	3	8
PASTORAL	6	8
BOSTONIAN	1	9
EMOTIONAL	68	9
PEDIGREEC	1	9
RADIANT	8	7
FILTHY	7	6
BRIGHT	87	6
MEXICAN	24	7
BEASTLY	0	7
DRY	68	3
MILITARY	212	8
MERRY	8	5
VICTORIAN	8	9
FAVOURABI	0	10
WHITE	365	5
CLAMMY	2	6
ETHNIC	13	6
COURAGEC	4	10
RUSTIC	3	6
RICH	74	4
SHADOWY	1	7
SYRIAN	1	6
PERSONAB	0	10
UNIVERSAL	45	9

DUMPY	0	5
ANCIENT	69	7
USUAL	96	5
FUTURE	227	6
PASSIONAT	12	10
ANTISOCIAL	2	10
ABUNDANT	9	8
NATURAL	156	7
EXCLUSIVE	28	9
MOROSE	2	6
NORMAL	136	6
AGILE	2	5
BLUE	143	4
DULL	27	4
WEAK	32	4
WEIRD	10	5
ARMENIAN	1	8
GLOOMY	3	6
CORDIAL	6	7
FOUL	4	4
JAPANESE	53	8
RAW	43	3
HANDSOME	40	8
SHADY	1	5
EUROPEAN	61	8
SOUTHERN	137	8
PECULIAR	27	8
DEEP	109	4
HEINOUS	0	7
MISERABLE	13	9
DEVOID	6	6
THRIFTY	3	7
CURRENT	104	7
JOYOUS	5	6
LIQUID	48	6
OPPRESSIV	4	10
CUNNING	5	7
CHEESY	0	6
PUPAL	0	5
NAVAL	33	5
FOREIGN	158	7
EERIE	2	5
WELCOME	50	7
OUTLANDIS	1	10
BENIGN	1	6
DILIGENT	2	8
POSTAL	7	6
IMPOSING	7	8
SWEET	70	5
EVERYDAY	12	8
FUZZY	7	5
IMPOSSIBLE	84	10
GRIM	14	4
SCHOLASTI	9	10
OLD	660	3
EPIC	18	4
COSMIC	18	6

JUDICIOUS	1	9
ALIVE	57	5
CORRUPT	8	7
HOMOSEXU	2	10
LITTLE	831	6
JUVENILE	18	8
LEGENDAR	6	9
MORBID	1	6
CLIMACTIC	4	9
FULL	230	4
DEAD	174	4
NAUTICAL	2	8
BRITTLE	3	7
POLITICAL	258	9
TYPICAL	65	7
VENEZUELA	2	10
HISTORIC	23	8
TECHY	0	5
BETTER	414	6
OMNIPOTEN	0	10
UNCULTURI	0	10
GREASY	8	6
CANADIAN	7	8
CHINESE	56	7
BANKRUPT	5	8
SECRETIVE	0	9
CHERUBIC	0	8
SADISTIC	2	8
ACTIVE	88	6
PIOUS	10	5
AERONAUT	0	10
AGED	18	4
INFANTILE	2	9
DOMINANT	65	8
CULINARY	0	8
CATHOLIC	84	8
SIBERIAN	1	8
EXQUISITE	3	9
MAGICAL	12	7
EVEN	1171	4
ASHEN	2	5
PLEASANT	38	8
MOTHERLY	1	8
OBSCURE	17	7
SOPHISTIC	0	9
EVIL	72	4
SKETCHY	0	7
GOTHIC	4	6
POLISH	19	6
PROTECTIV	14	10
CONTAGIOU	2	10
OBSCENE	2	7
UNBECOMI	0	10
DOCILE	4	6
TRAGIC	33	6
SURGICAL	1	8
EASYGOING	1	9

SEVERE	39	6
GHASTLY	6	7
EXECUTIVE	55	9
ILLCIT	3	7
MYSTICAL	5	8
ARTISTIC	33	8
RIDICULOU:	19	10
MORTAL	10	6
SIAMESE	4	7
DECORATIV	8	10
MONUMENT	5	10
RUDE	6	4
IRISH	28	5
ADMIRABLE	10	9
ALOOF	5	5
TAME	5	4
VIENNESE	1	8
SEXUAL	59	6
EROTIC	8	6
HEROIC	21	6
IMMIGRANT	4	9
INAUGURAL	8	9
HIDEOUS	11	7
STATUESQI	0	10
PLAIN	48	5
POIGNANT	6	8
ROWDY	4	5
DROLL	0	5
CHORAL	2	6
EVERGREE	1	9
PATERNAL	0	8
UNSAFE	1	6
AQUATIC	0	7
NAUGHTY	1	7
AIRBORNE	7	8
TRASHY	0	6
OFFENSIVE	8	9
FUNNY	41	5
FELINE	2	6
HAPPY	98	5
BRAVE	24	5
DISTANT	37	7
VICIOUS	17	7
RIPE	14	4
CELTIC	7	6
UNIQUE	58	6
UNKEMPT	1	7
SENATORIA	3	10
DANGEROU	46	9
NATIVE	46	6
RADICAL	30	7
EFFICIENT	32	9
NOVEL	59	5
BRAWNY	0	6
UNREFINED	0	9
TERRIBLE	45	8
WOMANLIKI	0	9

AWESOME	4	7
FABULOUS	6	8
DENTAL	12	6
CHIC	7	4
RICKETY	1	7
SLUMMY	0	6
PATIENT	86	7
STRICT	11	6
IMPURE	0	6
SPLENDID	20	8
LEARNED	117	7
VAIN	10	4
ALPINE	0	6
QUIET	76	5
DWARFISH	0	8
ADOPTIVE	0	8
ENORMOUS	37	8
DISTINCT	42	8
FOOLISH	16	7
THIN	92	4
SEDENTARY	1	9
HEALTHY	33	7
BITTER	53	6
TENDER	11	6
COMPLEX	91	7
AFFABLE	1	7
LOVABLE	2	7
GREEN	116	5
DORMANT	5	7
SPANISH	36	7
ILLUSORY	2	8
ALCOHOLIC	3	9
FUNKY	0	5
PAROCHIAL	12	9
ELDERLY	13	7
UNMANLY	0	7
GARISH	1	6
SCUMMY	0	6
PROUD	50	5
SENIOR	34	6
EMPTY	64	5
AFLOAT	7	6
CRAFTY	1	6
BRIDAL	2	6
TRIUMPHANT	5	10
INDECENT	5	8
CONCRETE	48	8
PRIMITIVE	38	9
DERELICT	1	8
AMICABLE	1	8
NEEDY	6	5
MODERN	198	6
HAWAIIAN	6	8
FRAIL	8	5
ROMANTIC	32	8
STARRY	0	6
ROBOTIC	0	7

ALONE	195	5
EGYPTIAN	5	8
RUGGED	19	6
GODLY	0	5
SPIRITUAL	64	9
EARTHY	10	6
FAMILIAR	72	8
SLOPPY	3	6
VIVACIOUS	3	9
DIPLOMATIC	28	10
ADORABLE	3	8
ADAPTABLE	2	9
HOLY	49	4
HILARIOUS	2	9
MUGGY	1	5
COMMERCIAL	61	10
LUCKY	21	5
ATYPICAL	1	8
GIRLISH	5	7
BLIND	47	5
INEBRIATE	0	9
PROPER	95	6
MYSTERIOUS	26	10
SUNNY	13	5
HYSTERICA	10	10
GORGEOUS	7	8
DELICATE	27	8
CORPORATE	19	9
SEASICK	0	7
ORNATE	1	6
AWARE	84	5
ITALIAN	47	7
ABYSMAL	2	7
CLINICAL	27	8
OFFICIAL	75	8
UNWOMANLY	1	9
PATHOLOGICAL	1	10
FEUDAL	6	6
LATE	179	4
ASIAN	10	5
SAVOURY	0	7
FLAMBOYANT	3	10
FANCY	16	5
ABNORMAL	3	8
CLEAN	70	5
PERFECT	58	7
FEDERAL	246	7
MEDIEVAL	18	8
FOND	13	4
ALGERIAN	5	8
SATANIC	0	7
RESIDENT	13	8
YOUNG	385	5
RECENT	179	6
DEGENERATE	0	10
INTIMATE	21	8
DESIRABLE	36	9

UNTIDY	1	6
DYNAMIC	21	7
GREEK	61	5
SOFT	61	4
EXCESSIVE	30	9
VIVID	25	5
FERTILE	5	7
CERAMIC	9	7
SICILIAN	3	8
BROAD	84	5
ALMIGHTY	5	8
UKRAINIAN	3	9
GLAMOROU	5	9
MEDIOCRE	5	8
ALERT	33	5
UGLY	21	4
HONORABL	#N/A	###
FRIENDLY	61	8
ARCTIC	4	6
CONFIDENT	16	9
FORMAL	48	6
ASYMMETR	2	10
CLEAR	219	5
ARTIFICIAL	17	10
AIRTIGHT	0	8
HELLISH	0	7
RUSSIAN	80	7
SCANDALOI	0	10
ROTTEN	2	6
AMORPHOL	6	9
ORIENTAL	16	8
ACOUSTIC	1	8
MELLOW	1	6
FLUFFY	1	6
ANGULAR	16	7
OUTGOING	8	8
NATIONAL	375	8
CLOSE	234	5
EXPRESSIV	7	10
DRAB	5	4
SNOWY	4	5
WET	53	3
GOLDEN	42	6
BARREN	7	6
BRUTAL	7	6
TIMID	5	5
CHILLY	5	6
TECHNICAL	120	9
VACANT	11	6
AFRICAN	28	7
HAZY	5	4
MASSIVE	33	7
FRAGILE	10	7
UNFRIENDL	6	10
ADULT	25	5
SQUARE	143	6
YELLOW	55	6

STRAIGHT	114	8
SCARLET	3	7
FRESH	82	5
VILLAINOUS	1	10
AERIAL	8	6
OUTRAGED	2	10
FANTASTIC	20	9
SMART	21	5
UNPLEASANT	15	10
AUSTERE	5	7
ICY	12	3
BARBARIC	1	8
DUSTY	16	5
WICKED	9	6
UNCIVIL	1	7
ZEALOUS	4	7
DUSK	9	4
SMELLY	0	6
EASTERN	32	7
CHAOTIC	5	7
SLEEPY	6	6
CONGENIAL	7	9
SHOWY	1	5
EXOTIC	7	6
ARABIC	6	6
PAST	281	4
DOMESTIC	63	8
RURAL	54	5
INSANE	13	6
CAPITAL	85	7
CIRCULAR	21	8
DELINQUENT	6	10
VIETNAMESE	6	10
REGAL	2	5
SECULAR	16	7
CELESTIAL	8	9
ISLAMIC	3	7
ENDURABLE	2	9
TENSE	15	5
JUNGLY	0	6
RIGID	24	5
WESTERN	137	7
SOBER	19	5
PATRIOTIC	10	9
PERVERSE	5	8
CUTE	5	4
LIVELY	26	6
SEASONAL	8	8
HARMONIOUS	5	10
BANAL	2	5
DIRTY	36	5
MANLY	2	5
WORLDLY	9	7
CROOKED	3	7
IRANIAN	0	7
BLAND	3	5
ACCURATE	35	8

STRANGE	84	7
COPIOUS	1	7
RIOTOUS	2	7
FAVOURITE	0	9
ALGEBRAIC	1	9
LEGAL	72	5
PESKY	0	5
ASTROLOG	0	10
NASTY	5	5
LONELY	25	6
AFFLUENT	2	8
BOTANICAL	1	9
OMINOUS	12	7
URBAN	42	5
ATTRACTIV	39	10
FADDISH	0	7
ELEGANT	14	7
CANINE	1	6
ANAL	0	4
GROTESQU	9	9
SPECIAL	250	7
DESOLATE	6	8
SOLITARY	14	8
CHAMPION	23	8
BRISTLY	0	7
BIZARRE	7	7
CHILDISH	11	8
INTACT	14	6
UNHEALTH	4	9
HORRID	1	6
BELGIAN	14	7
ACADEMIC	56	8
REPUBLICA	54	10
DARK	185	4
DEMOCRAT	109	10
AMERICAN	569	8
OBSOLETE	5	8
NERVOUS	24	7
AMBITIOUS	16	9
BUOYANT	2	7
DEATHLY	1	7
INDIAN	52	6
WILD	56	4
DEFICIENT	3	9
HYPNOTIC	1	8
ACROBATIC	2	9
BRILLIANT	50	9
NOISY	6	5
CHEAP	24	5
PRETTY	107	6
SANITARY	4	8
ORIGINAL	103	8
ABSTRACT	34	8
AMAZONIAN	0	9
LUNAR	10	5
BOHEMIAN	1	8
COLLEGIAT	4	10

FRUMPISH	0	8
MONOCHRO	0	10
SERIOUS	116	7
PERFUMED	2	8
HISTORICAL	71	10
MAJESTIC	10	8
ROUGH	41	5
ABUSIVE	1	7
DISORDERL	3	10
SCRAPPY	0	7
IMPERIAL	13	8
STATELY	4	7
RIGOROUS	7	8
EXTERIOR	8	8
AROMATIC	2	8
AGRARIAN	8	8
PLACID	6	6
SWEDISH	7	7
FAIR	77	4
COOL	62	4
MASCULINE	7	9
ASSYRIAN	2	8
AESTHETIC	26	9
FEMININE	10	8
CENTENNIA	6	10
GRAVE	33	5
AMATEURIS	3	10
SAFE	58	4
QUEASY	0	6
COLD	171	4
BOVINE	2	6
MALICIOUS	2	9
NEUROTIC	10	8
LOUD	20	4
SMOOTH	42	6
CHARITABL	5	10
SCOTTISH	10	8
STILL	782	5
TIDY	1	4
MUSCULAR	16	8
UTOPIAN	21	7
MANIACAL	1	8
HOT	130	3
BARE	29	4
LITERARY	78	8
ABLAZE	3	6
ATHLETIC	18	8
MEMORABL	11	9
FLAT	67	4
AUSTRALIA	9	10
MONGOLIAN	0	9
DECADENT	2	8
DEMONIC	0	7
BOTHERSO	1	10
CLOUDY	2	6
CLERICAL	9	8
NARROW	63	6

SNOBBISH	2	8
FINAL	156	5
IDYLLIC	4	7
STERILE	9	7
ANTIVIRAL	0	9
ANTIQUE	12	7
MUNDANE	3	7
GENTLE	27	6
COMPACT	12	7
PRECIOUS	29	8
LEWD	3	4
FRUITY	0	6
THEATRICAL	12	10
CREATIVE	49	8
BASE	91	4
BOURGEOIS	3	9
MARINE	55	6
STYLISH	1	7
ALBANIAN	2	8
REPTILIAN	0	9
WARY	7	4
BLONDE	20	6
CROSS	55	5
AFLAME	3	6
AMPHIBIOUS	1	10
BROTHERLY	2	9
BEACHY	0	6
SAD	35	3
EXTINCT	1	7
JEWISH	74	6
DRIZZLY	1	7
NEAT	21	4
VAGRANT	1	7
CHEERY	3	6
HUMOROUS	16	8
NOTORIOUS	8	9
ACCUSATORY	0	10
DESERT	21	6
FRUGAL	0	6
BEAUTIFUL	127	9
POSH	0	4
CLEVER	17	6
FRIGID	5	6
GRASSY	2	6
ARID	2	4
IMMATURE	7	8
YIDDISH	4	7
CHRISTIAN	144	9
DREARY	6	6
FAMOUS	89	6
SALTY	4	5
WINTRY	2	6
BIBLICAL	18	8
EMBRYONIC	2	9
ARABIAN	2	7
REPULSIVE	4	9
CASUAL	22	6

HOLLOW	12	6
VAGUE	25	5
IMPECCABL	6	10
CHIEF	119	5
BELOVED	18	7
FAINT	25	5
WEALTHY	12	7
DEVILISH	3	8
MESSY	3	5
BRAINY	1	6
SANDY	6	5
TALL	55	4
PROMINENT	40	9
ETERNAL	29	7
ANNUAL	93	6
HOSTILE	19	7
STARK	7	5
BISEXUAL	0	8
ARCHAIC	5	7
WIDE	125	4
CAUCASIAN	1	9
CYNICAL	9	7
EQUESTRIA	0	10
ENGLISH	195	7
SODDEN	2	6
WARLIKE	5	7
DISASTROL	16	10
RAGGED	9	6
SICK	51	4
SENILE	2	6
TUNISIAN	3	8
AWFUL	17	5
INTENSE	40	7
SOGGY	3	5
POMPOUS	3	7
JAMAICAN	1	8
FAST	78	4
SCANT	5	5
DEVOTIONA	1	10
ANIMATE	1	7
CAPTIVE	5	7
ANGELIC	2	7
SHALLOW	14	7
SUMMERLIK	0	10
GERIATRIC	1	9
DRAMATIC	63	8
OPEN	319	4
OUTDOOR	27	7
PURE	56	4
DIVINE	34	6
RACY	2	4
DREAMY	4	6
ECCENTRIC	11	9
MATERNAL	5	8
SCIENTIFIC	86	10
AUTHENTIC	20	9
HECTIC	3	6

FERAL	0	5
BOYISH	4	6
MELODIC	5	7

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