Detecting Consciousness with MEG: A selective attention paradigm for communicating with immobile (locked-in) children and adults

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ABSTRACT

How can we tell if an unmoving person is conscious? Owen *et al*'s[1] method of looking for normal fMRI brain responses to complex tasks (imagine playing tennis vs. imagine walking through a house) has been criticized on the grounds that processing does not necessary imply consciousness. Egeth[2] proposes that *communication* requires volitional brain activity and thereby implies consciousness: if a person can alter his brain state in order to answer a question, such as by imagining playing tennis to answer yes or imagining a house to answer no, and proceeds to answer questions normally, then we would be hard pressed to deny the attribute of consciousness to that person. In order to use communication to establish consciousness, rather than finding complex mental tasks for patients to engage in, we can instead search for relatively simple tasks that a patient can use as a code to communicate "yes." Many extant tasks could be adapted for this purpose; here, we ask neurotypical subjects to alternately listen to and ignore blocks of soft tones (Experiment 1), and one subject attempts to selectively listen in order to deliberately communicate a message (Experiment 2). Experiment 3 describes a communications paradigm intended specifically for children, Essentially, if we can detect that a person has made a choice, we can infer that the person is conscious.

KEYWORDS: MEG, BCI, Turing Test, Consciousness, Vegetative, Coma, Comatose, Locked-In, Auditory, Attention

INTRODUCTION

Brain-computer interfaces (BCIs) have had exciting but limited success allowing locked-in (conscious but immobile) adults to communicate, and none have been reported to work for locked-in children. Most BCIs require extensive practice. In addition, in spite of Owen *et al*'s[1] report that some might be conscious; the field has not reported successful communication with people diagnosed as comatose or vegetative. Here, we hope to provide new, user-friendly methods of communication that do not require practice, that children could use, and that might be used to identify consciousness among seemingly unconscious comatose or vegetative people. We focus on early evoked neural responses that can tell us where a subject has chosen to pay attention and which children are known to exhibit.

METHODS

Experiment 1

MEG recordings from a CTF 275-channel whole-head biomagnetometer were collected. Three subjects experienced 16 blocks of 50 200ms 200Hz tones in the right ear with an 800ms +-10ms ISI and 10 seconds between blocks; subjects were asked to close their eyes during the experiment to minimize eye-blink artifacts. Before each block, subjects were asked to either ignore or listen to the tones; the ignore/attend instruction alternated with each block, starting with ignore, resulting in 400 trials of each condition per subject.

Experiment 2

The third subject from Experiment 1 returned for a subsequent session to attempt to communicate a concept (a vegetable of her choosing) through yes/no answers. The experimenter asked "yes or no" questions from the neural network 20-questions website, 20q.net, which plays the game "Animal, Vegetable or Mineral?" Each question was followed by two blocks of 50 tones. The subject was instructed to listen to the first block of tones to indicate "yes" or ignore the tones to indicate "no," and then *to switch tasks for the 2nd block*. This method provides a contrast condition for each question: if the first block is attended, the answer is "yes"; if the second block is attended, the answer is "no."

CTF real-time MEG data outputs were configured to display averages for "Condition 1" (the first block) and "Condition 2" (the second block). Subject 3 showed more time-locked activity during the attended condition in Experiment 1; for Experiment 2, the experimenter (M.E.) provided 20q.net with "yes" and "no" responses by making an estimate after each block whether Condition 1 or Condition 2 showed more such activity and, thus, revealed the subject to be paying attention.

Experiment 3

Subject 1 from Experiment 1 listened to dichotic streams of a female saying "yes" (left ear) and a male saying "no" (right ear) with loudness deviants randomly distributed within each stream; the subject alternated blocks attending to the yeses and the nos. This method creates a more natural code by which to answer "yes" and "no:" instead of attending to tones, subjects can listen to the yeses to communicate "yes" or listen to the nos to communicate "no." Attentional mediation of the mismatch field is expected to distinguish between a subject attending to the yeses versus attending to the nos; such effects have been reported for both adults and children.[3]

RESULTS

Experiment 1

All subjects showed recognizable time-locked auditory responses to tones (M100) for both attended and ignored conditions. In addition, all subjects showed time-locked differences to attended versus ignored tones in right posterior brain regions, both prior to and following the tone (see Fig. 1 for difference waves and Fig 2. for one subject's "attended" and "ignored" time-locked waveforms.)

DIFFERENCE WAVES, ATTENDED MINUS IGNORED

100ms pre-tone to 0ms **50 to 150ms post-tone onset**

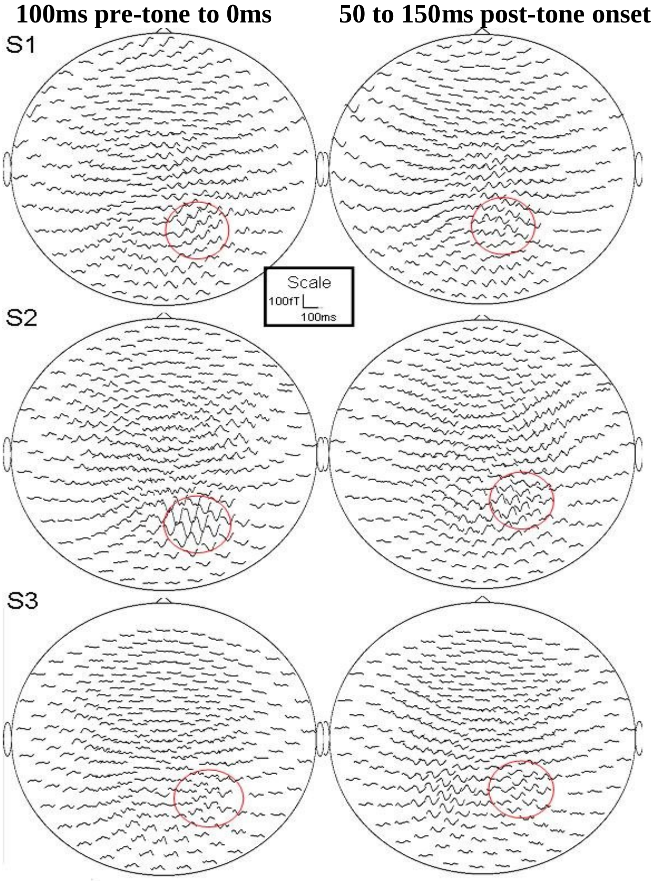

Fig 1. Three subjects show differential neural activity while listening to vs. ignoring 200Hz tones in the right ear, both before the tone (left) and after the onset of the tone (right). For each line, deviation from straight indicates a difference in magnetic flux between ignore and attend conditions. The most consistent difference appears to be right posterior activity (in circles).

Experiment 2

After starting with "vegetable" in the game "Animal, Vegetable or Mineral," 20q.net provided "yes or no" questions in an iterative manner based on the experimenter's inputs (see Table 1).

After 18 yes/no responses provided by the experimenter, 20q.net guessed "lime" and "ginger root." However, the subject reported choosing "carrot" and that the procedure misidentified responses 4 and 18. In spite of the failure to deduce "carrot," 16 out of 18 correctly transmitted yes/no responses represents above-chance communication through the MEG interface ($p < .01$). Figure 2 shows Subject 3's averaged attended and unattended response by brain region from Experiment 1 in a format similar to the real-time outputs used in Experiment 2 as well as averaged responses from a representative question in Experiment 2.

WAVEFORMS GROUPED BY BRAIN REGION

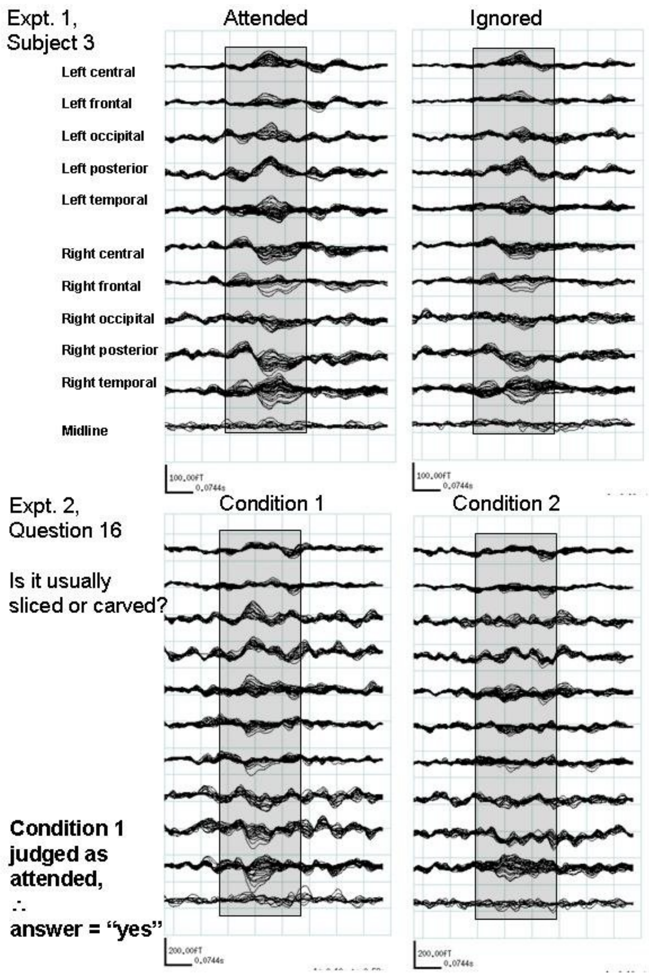

Fig 2. Subject 3's averaged response to tones by brain region from 100ms pre-tone to 500ms post-tone from Experiment 1 (top) and one question from Experiment 2 (bottom). Attending during Condition 1 means "yes," which, based on the amount of time-locked activity around 100ms (grey boxes) is what the subject appears to have done.

Table 1. Yes/No questions from 20q.net and responses based on real-time analysis of MEG data. Errors are marked with an asterisk.

1. Is it green?	(no)
2. Is it classified as a Vegetable?	(yes)
3. Can it bend without breaking?	(no)
4. Is it used to make salads?	(no) *
5. Can it discharge waste?	(no)
6. Do you hold it when you use it?	(yes)
7. Is it smaller than a loaf of bread?	(yes)
8. Does it have lots of seeds?	(no)
9. Does it taste sweet?	(no)
10. Is it hard?	(yes)
11. Does it have leaves?	(no)
12. Can it be used more than once?	(no)
13. Can you order it in a restaurant?	(yes)
14. Does it have a hard outer shell?	(no)
15. Is it smooth?	(yes)
16. Is it usually sliced or carved?	(yes)
17. Does it taste good with butter?	(no)
18. Can it be used to season foods?	(yes) *

Experiment 3

Following 1000 attended and 1000 unattended simultaneous presentations of the words “yes” and “no” with 20% randomly distributed loudness deviants (-5dB) within each stream, neural differences to attended vs. unattended deviant “yeses” appeared bilaterally in frontal and temporal regions (see Figure 3).

RESPONSE TO DEVIANT YESSES

While attending to yes   While attending to no

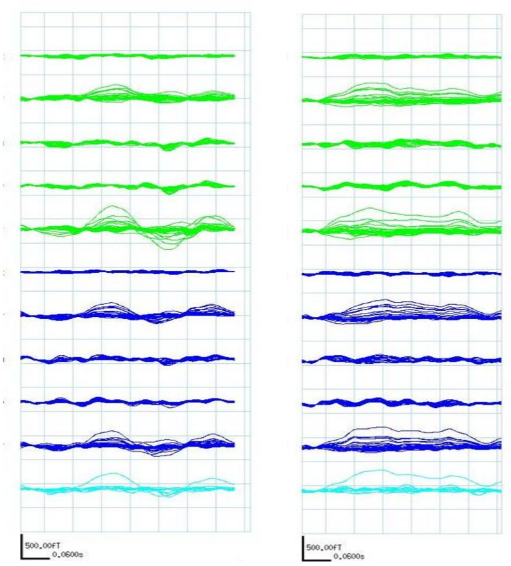

Fig 3. Subject 1 shows differential neural activity for deviant exemplars of the word “yes” depending on whether he is listening to the word “yes” in his left ear or listening to the word “no” in his right ear. Sensor groups depicted are the same as in Fig.2 (central, frontal, etc.)

DISCUSSION

Numerous attentional tasks are known to elicit functional brain differences; many of them could be adapted for locked-in communication. Here, we find neural difference within-individuals for a small number of subjects who complete a basic task from the attention literature – attend to an auditory stimulus. Three subjects showed similar neural differences for selectively paying attention to a tone (Exp. 1); one subject was able to convey, if somewhat imperfectly, a number of choices of the answers “yes” and “no” (Exp. 2); and one subject showed distinct neural differences while using a user-friendly paradigm designed to elicit measurable neural differences in children based on their direction of attention (Exp. 3).

Completely ignoring a tone which is the only sound (Exp. 1 and 2) might be impossible. For “ignore” strategies, subjects reported listing the names of states and mentally reciting memorized texts. The key here is that subjects during the “ignore” conditions are, at least, not listening as closely as during the “attend” conditions. Exp. 3 shows an alternate method that does not require subjects to actively ignore a salient stimulus but, rather, to choose which of two stimuli to pay attention to.

CONCLUSION

Our new selective attention procedures, especially the yes/no procedure described in Exp. 3, are, to our knowledge, the first procedures designed to detect a choice made by a locked-in child, and here we find our new paradigms to be effective with neurotypical adults.

Following Owen *et al*’s method of establishing the presence of consciousness, the more complex a mental task a patient can perform, the more likely the patient is to be conscious. However, it is not clear to what degree unconscious processes might account for complex brain activity. Instead, here we find simple tasks that a patient could use *to communicate*: detecting that a patient has made a choice, even if the choice is between two simple mental tasks, would efficiently and definitively establish the presence of consciousness.

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