NeuroSky's eSense™ Meters and Detection of Mental State

The "Attention" and "Meditation" eSense meters output by NeuroSky's MindSet are comprised of a complex combination of artifact rejection and data classification methods. Here we present a study testing the meters to determine their sensitivity to higher cognitive mental states. We demonstrate that the meters are able to differentiate between certain mental states.

Introduction and Background

The future of EEG research lies in the mobile recording and real time feedback of emotional and cognitive states. While in the research community there is a focus on developing complex headsets using multiple channels, in the short term, the widespread use of EEG technology by the general public is most likely going to rely on inexpensive, easily usable (mobile, gel-free), single channel acquisition.

Because of volume conduction (the ability to measure electrical potentials at a distance from their source generators), single channels, irrespective of where they are placed on the scalp, are able to capture a large fraction of the entire brain's dynamics [1]. The forehead is a convenient location for placing a single contact sensor; it avoids the problem of achieving a good connection through hair, and it is over the frontal cortex where cognitive signals linked to higher states of consciousness originate.

NeuroSky's MindSet is a headset using a single contact sensor on the user's forehead. Along with having the ability to record raw EEG data, the MindSet is able to output two custom measures: "Attention" meter values, which indicate the user's level of mental focus, and "Meditation" meter values, which indicate the level of a user's mental calmness. Together, these meters are referred to as NeuroSky's eSense meters.

Methods

Fourteen subjects volunteered for the study (10 males and 4 females). Subjects sat in a comfortable chair in front of a LCD computer screen wearing the NeuroSky MindSet. The LCD screen was controlled by a laptop computer connected to the MindSet through a Bluetooth serial connection.

Data acquisition and visual display were all run from a Matlab program under the Windows platform. The single MindSet sensor was most often situated two centimeters above the eyebrow. It was not our intention to precisely calibrate the headset for each individual, as this would not have reflected real use by potential customers. Instead, users put on and adjusted the headset themselves, with the simple verbal instruction “place the sensor of the MindSet on your forehead”.

Data acquisition was performed using the Matlab-based NeuroSkyLab program, a proprietary tool developed by NeuroSky (available for research and development in the NeuroSky store), and recorded using the commercially available MindSet Pro unit (128 Hz sampling rate). The headset currently available for sale in the NeuroSky store is the MindSet unit (virtually identical except for a much faster 512 Hz AD conversion and sampling rate).

During the test, the subject was instructed to generate 5 different mental states. For brevity’s sake, we will focus on two states: “Neutral” and “One with the Dot”. During the “Neutral” state, the subject was instructed not to engage in any type of relaxation or concentration exercise, and to try to keep their mind in a neutral type of state. During the “One with the Dot” state, the subject was instructed to fixate on a dot on the screen and imagine their breath coming in and out of that dot so as to promote a relaxed and meditative state of mind. All states were performed with the subject’s eyes open and with a mark on the screen (if only for the subject to rest their eyes on).

Before the subject was required to produce each state, oral instructions were played by the computer. Following these instructions, the subject would attempt to produce that mental state for 40 seconds. Each state was repeated 4 times, with a random state order.

Data Analysis

Every second, the headset computes and delivers the Attention and Meditation eSense measures. These measures are trade secrets and cannot be described here. Our purpose was to test if these measures co-varied with the state the subject was asked to produce.

To take into account the fact that the subjects may need some time to reach each state, we removed the first 10 seconds of data from each 40-second data segment. The headset has noise filters in place in order to ensure any noise (head movements, muscle artifacts etc.) is filtered out of the raw EEG before the calculation of the eSense values. A separate paper will be published by NeuroSky regarding noise removal and eSense in this specific experiment. When the headset detects bad data that produces too much noise to be filtered out properly, the same meter value is repeated. Thus all meter values that were consecutive and equal were removed. We then applied parametric and non-parametric statistics to test for significant differences between conditions.

Electrophysiological Results

The states considered, “Neutral” and “One with the Dot”, were designed to record the subject in a neutral state and in a more meditative state, respectively. Naturally, one would expect the Meditation meter to pick up on the differences between these two states. As discussed below, a strong, statistically significant difference for the Meditation meter values was found in these two states, and this was observed for 9 out of 14 of subjects. In addition, we obtained classification performance up to 86%, which means that we were able to tell 86% of the time which of the two states a subject was in (on average). These results are encouraging, and show that the MindSet unit has the potential not only to record brainwave activity, but also to differentiate between mental states. Below, we describe these results in more detail.

To obtain these results, we first compared the Meditation meter output of the headset for all subjects in the different states. A two-tailed t-test (df=13) was run to test if the difference of the meter values between each of the states was significantly different from 0 (p=0.00017). We also tested for non-normal distribution using the Kolmogorov-Smirnov goodness-of-fit test. All distributions tested in this report were not significantly different from normal. Different statistical tests were then used to test the robustness of our results: we used the Wilcoxon test, the sign test, and the t-test to compare the mean meter value for both states. Finally, we used permutation and bootstrap statistics. All tests returned significant results. The least significant p-value was 0.0068 (df=13; t-test on the mean). Note that comparing the mean meter value will produce less significance than testing if the difference between the two states was 0, since different subjects had different ranges of values (some having their Meditation measure varying between 40 and 50, others between 50 and 70). We used all of these different statistical tests to ensure that our results are reliably significant, irrespective of what test is being used.

Following this state comparison, we studied each subject individually. As seen in Table 1, 9 of the 14 subjects showed a significant difference for the Meditation meter between the “Neutral” and “One with the Dot” state. All subjects that had significant results had a value for the Meditation meter that was higher in the “One with the Dot” state as compared to the “Neutral” state. Figure 1 shows an example histogram of one subject’s Meditation meter values when practicing the two states. We can clearly see the difference between the two states.

Table 1. All subjects' mean Meditation value and significance results between the "Neutral" and the "One with the Dot" states.

	Neutral	One WD	p-value
s1	63,2	62,6	ns
s2	58,2	64,1	0.0016
s3	52,5	58,2	0.0008
s4	46,6	66,3	0
s5	54,5	58,4	ns
s6	47,3	49,2	ns
s7	63,1	61,3	ns
s8	52	59,4	>0.0001
s9	58,4	63,1	0.0016
s10	47,5	54,2	>0.0001
s11	55,5	62,9	>0.0001
s12	57,3	57,2	ns
s13	51,7	56,8	0.0002
s14	57,6	61,4	0.0318

ns – non-significant

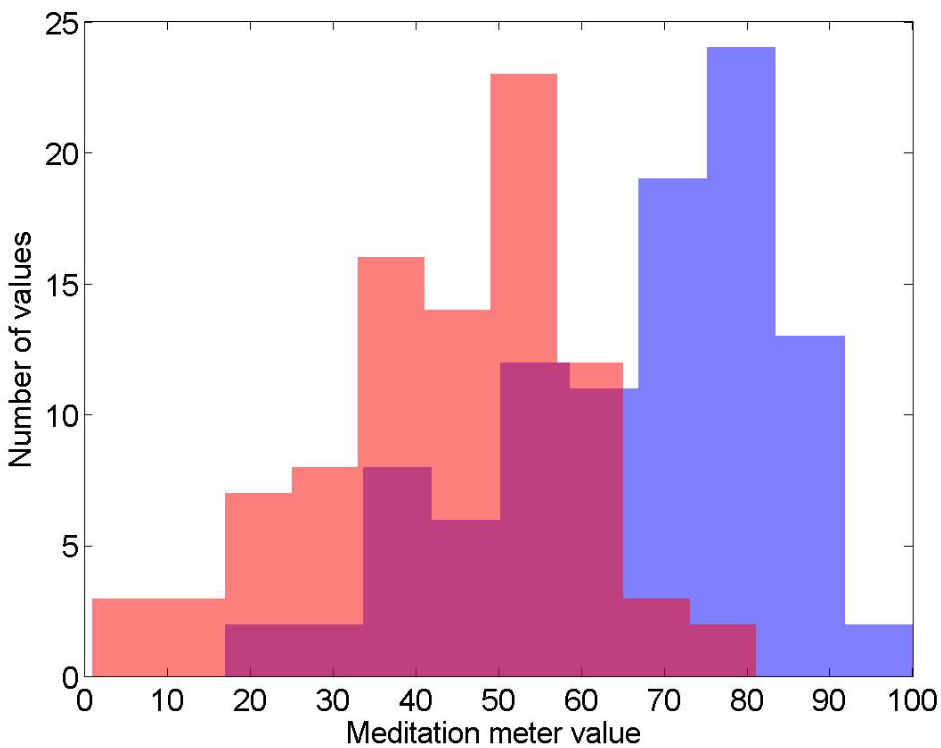

Figure 1: Example histogram of one subject's Meditation eSense measure pooled over the 4 40-second sessions: pink is "Neutral" and blue is "One with the Dot".

We also performed a basic two-class classification using the collection of all Meditation meter values from each subject. We used cross-validation across subjects (leaving one subject out during optimization) and optimized a lower and an upper meter threshold. This cross-validation method allows for unbiased classification, since the training data is not included in the performance evaluation. If the Meditation meter value was above the upper threshold, then we counted one vote for the “One with the Dot” state. If the Meditation meter was below the lower threshold, we counted one vote towards the “Neutral” state. We then summed all the votes for each of the states, and the state that had the most votes was selected. Using all subjects but one, we optimized the upper and lower thresholds using a Nelder-Mead simplex method [4]. We then tested the classifier on the remaining subject. Again we repeated the procedure for each subject and subsequently averaged over subjects to compute the global accuracy.

Classification accuracy was assessed using baseline corrected Meditation meter values, where we removed the mean Meditation meter value from each subject. Between the “Neutral” and the “One with the dot” state, we obtained a classification accuracy of 86%.

Discussion

This report is a proof of concept that when using the standard output from the NeuroSky MindSet, despite the low-cost oriented design (when compared to several thousands of dollars for clinical and research EEG systems), we can clearly and reliably differentiate between higher states of consciousness.

It is also important to emphasize that subjects did not train to produce such states or attempt to control the eSense meters, as they did not obtain real time feedback on the screen about their mental states. If subjects had trained to produce each of the states or had intended to control the meters, classification results would likely be better; yet regardless, with no training at all, the eSense meters are capable of mental state detection.

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