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DOI: 10.14293/S2199-1006.1.SOR-.PPELEFG.v1
Preprint first posted online: 13 February 2022
Keywords: cognionics hd-72, electroencephalography (EEG), wireless EEG, cognitive neuroscience, psychology, brain recording, neural activity, brain electrical potentials, eeg guidelines, dry and mobile EEG

Cognionics HD-72 Wireless EEG System:
A Noninvasive Method of Measuring the Brain's Electric Fields in Cognitive Neuroscientific Research

Technical Report

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Abstract

The primary goal in cognitive neuroscientific research is to investigate the underlying neurobiological mechanisms that inaugurate various behaviors and executive functions. A multitude of methodologies exists today that can be used to measure cortical electrical activities. Electroencephalography (EEG) has now been established as an essential noninvasive measure for investigating cortical electric fields. The use of Cognionics dry-mobile wireless EEG system has become widely popular in cognitive neuroscientific research due to its portability, ease of setting-up, and easy access to the raw data for further processing. This paper presents a brief guideline for exploiting Cognionics HD-72 wireless EEG systems in psychological research without incurring a performance penalty during data collection. A careful investigation of the components in the EEG system will allow researchers to utilize the system effectively when conducting EEG research.

Keywords: Cognionics, EEG, electroencephalography, brain recording, neural activity

INTRODUCTION

Electroencephalography (EEG) is a noninvasive brain imaging method that measures voltage deflections from the brain. EEG is widely used in cognitive neuroscientific studies due to its ability to detect voltage changes with high temporal precision. This is known as the temporal resolution (Andersen et al., 2019). Unlike other brain imaging techniques such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET), or magnetoencephalography (MEG), EEG will record the brain activity as a continuous process, starting before the presentation of the stimulus and extending beyond response selection. EEG is also relatively low cost and safe to use. Brain activities can be recorded in almost every person ranging from newborns to older adults. The most commonly used standard EEG system is the wet system, which connects electrodes to an EEG cap.

It is called a wet system because a high conductive electrolyte gel (such as Ag/AgCl) is applied between the electrode and the scalp to enhance the skin conductance between the scalp (skin) and the electrode. This is to maintain a low electrical resistance between the contacts (skin-electrode). The number of electrodes in the EEG system can vary from two electrode systems (known as the low-density EEG systems) to 256 electrodes (also known as high-density systems), depending on its application. Compared to low-density EEG systems, high-density EEG systems can target more specific neural activities and capture high-resolution spatial information (Robinson et al., 2017).

EEG is widely used in multiple research domains such as medicine (Smith, 2005), brain-computer interface research (Mcfarland & Wolpaw, 2017), and neuromarketing (Kumar & Roy, 2019). It is significant to have a minimum number of electrodes to improve the signal-to-noise ratio and source localization (Fatoorehchi et al., 2015; Jurcak & Dan, 2007). This is because EEG signals, in general, are susceptible to interference from minor head and body movements as well as from other external electrical interferences such as from cell phones and electrical wires in the room from where the data are being recorded. EEG-related research is traditionally conducted in a Faraday cage typically situated in a laboratory setting to overcome such electrical interference. During the data collection, participants are typically instructed not to make any head and body movements to minimize any noise (interference) in the data *due to movements*.

There are several downsides to using a conventional wet EEG system. For instance, electrodes in wet EEG systems are directly connected to an amplifier during the recording. This limits most of the studies to be conducted in an EEG-specific laboratory. Moreover, the *initial setting-up* of a conventional wet EEG system can also be time-consuming because it requires the participants' skin preparation, which can occasionally cause minor discomfort and skin irritations to the participants.

Furthermore, participants must travel to the testing site (usually a laboratory situated in the research facility or university). This can be inconvenient for both participants and researchers because prior authorizations and reservations of those labs are necessary from the relevant authorities. If multiple researchers are conducting several experiments in the same lab, this can be a hassle to the researchers to find a suitable time which is also convenient to the participants.

Working Principles of Cognionics HD-72 EEG System

Dry (and mobile) EEG systems are effective in overcoming many of the challenges (associated with the traditional wet EEG systems) that participants and researchers can potentially encounter during EEG data collection. With the advancements in the wireless integrated acquisition technology, wearables such as dry EEG are becoming popular in the brain-computer interface (BCI) research, in clinical diagnoses, and in real-time cognitive state monitoring. Wearable high density wireless dry EEG hardware such as the Cognionics HD-72 EEG system (see Figure 1) can also deliver quality signals similar to the research-grade conventional wired wet EEG systems.

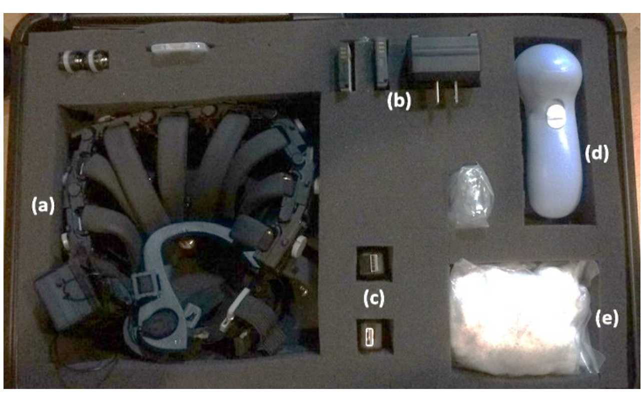

Figure 1: Cognionics HD-72 system (left). (a) the Cognionics (HD-72) 32 channel EEG unit, (b) batteries and the charging dock, (c) Bluetooth USB dongles for data transmission, (d) electric cleaning brush, (e) flex sensors and dry pad sensors. A participant is wearing the Cognionics 32-channel wireless EEG system (right).

Like a conventional wet EEG system, activities recorded from the Cognionics EEG system can deliver key predictive information regarding brain functions (and dysfunctions) based on intricate neural activities. Dry electrode systems do not use any electrolyte gel (hence, dry). Therefore, the preparation of the participants for the study is less time-consuming than a conventional wet system.

Electrode Sensors

There are two types of sensors used in the Cognionics HD-72 EEG system: *(1) flexible prong sensors* (known as flex sensors are made from flexible polymer coated with a conductive outer layer), and (2) *flat dry pad sensors* (see Figure 2). These sensors are easily removable for cleaning purposes and can be attached to the system via snap receptacles. Dry pad sensors are used in the forehead area. Dry pads consist of a semipermeable membrane and have a larger surface area for better contact. In contrast, flex sensors are used throughout the scalp to go through the hair of the participant touching the scalp for better conductivity.

Figure 2: Flex sensors (left), dry pad sensors (right)

In general, with dry electrodes, there will be no skin-related issues (which happens typically with wet electrodes due to the usage of gel). It reduces the probability of experiencing skin-related discomfort by the participants. However, due to the high sensitivity nature of the dry electrodes, they can generate electrical, physiological, or mechanical artifacts that can be easily hampered with the raw data - if the electrodes are not properly contacted with the skin (on the scalp). This issue is mitigated by an optimized electrochemical design in an integrated form factor.

One added advantage of the dry EEG systems over the wet EEG systems is the ability to conduct studies outside of a standard laboratory setting. This is because the Cognionics EEG system, for instance, can transmit its signals via Bluetooth technology (see Figure 3) to the receiving computer. It also does not require wires to connect to an external amplifier and does not require a Faraday cage to minimize interferences from electrical fields, making such systems far suitable to be utilized in field studies.

Figure 3: White arrow is pointed towards the Bluetooth transmission unit

Shielding

Electrical noises (typically observed as 50-60Hz line noise) recorded by EEG systems can be filtered out using a simple notch filter during post-offline processing. However, other forms of unpredictable noises can be at times harder to detect precisely. The Cognionics system utilizes an active ground system to cancel-out common-mode potentials (Mullen et al., 2015). The internal wiring system is enclosed in a miniature form of Faraday cage-like conductive layer across the headset, which is powered by the reference amplifier. This setup eliminates differential interference generally encountered as the high impedance with dry electrode systems. Potential DC offsets are handled by a high dynamic range input (400 mV), and a 24-bit ADC handles the AC-coupling, reducing potential amplifier saturation issues and minimizing large artifacts resulting from movements or sweating during the recording. The EEG system also consists of a real-time impedance monitoring method to actively monitor impedance levels in each electrode. This will help to identify any dysfunctional channels and adjust them accordingly before start recording of the raw data. When using the Cognionics EEG system, the channel status and the EEG waves are displayed in real-time to the researcher. Green status in the GUI indicates a perfect scalp-to-electrode connection, whereas red indicates no connection. It is considerably easier to adjust each individual electrode based on the channel status until the indicators turns green (see Figure 4).

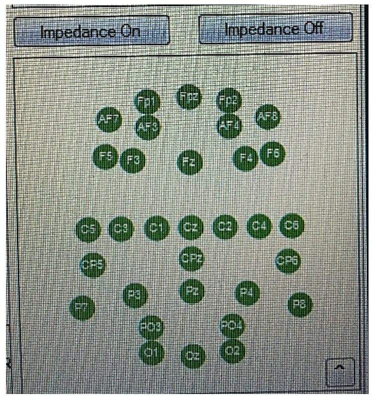

Figure 4: EEG channel. The green color indicates a good connection between the electrode and the scalp.

EEG systems are engineered to actively record brain activities while performing the task. Although the dry EEG systems are easy to use as they do not require the process of preparing the participant's skin in the scalp areas (with electrolyte gel), there is a high inter-electrode impedance that can reduce the signal-to-noise ratio - which can reduce its statistical power (Taheri et al., 1994). However, this is not a problem. In such cases, doing multiple test trials can increase its statistical power to detect a significant effect, and overcome the issue of impedance (Mathewson et al., 2017). Signals are then digitized at 300 samples (although they can be changed to 500 if needed) and transmitted via an onboard Bluetooth transmitter. Collectively, these steps will speed up the initial EEG setup. Event markers (triggers) are recorded via a secondary onboard radio signal transmission system (with a 2.4 GHz band coupled with a custom protocol) for precise timing detected via a USB receiver. The accuracy of the timing is less than 2ms.

In summary, dry EEG systems such as the Cognionics system are particularly advantageous when conducting field studies (outside traditional laboratory settings). The system is also highly dependent on advanced mechanics to provide a superior conductivity between the sensors and the participants' neural responses. The Cognionics HD-72 32-channel EEG system also employs a flexible adjustable plastic spine connected with elastic bands that continue laterally for easy and quick adjustments when placed onto the participant's head.

The following section will provide some necessary key information when utilizing the Cognionics HD-72 system (with 32-channels) in EEG research. The information related to the

EEG system is divided into three sections which include before, during, and after the data collection.

Guidelines for Using Cognionics Wireless HD-72 EEG System

As more dry EEG systems are being utilized in psychophysiological research, and the accessibility for such systems is gaining popularity due to the convenience of using wireless EEG systems. However, attention should be given to several measures during the data collection. The following section is divided into three parts. Part one will consist of information needed prior to the EEG data collection, such as carefully preparing the Cognionics headset and the participant. Part two will consist of the details necessary to maintain optimum signal strengths during the data collection. Finally, part three will provide the necessary information on removing and storing the EEG headset after the data collection is over.

Part 1

Prior to the Data Collection

- *Participant Preparation*

There are differences between preparing participants for studies that utilize dry EEG and wet EEG systems. Ideally, short-haired participants should be informed not to wear any hair products (such as hair gel, hair cream, etc.) prior to the study. For long-haired participants, they should be informed not to tie their hair and *"let it loose",* so that *(especially)* the sensors in the occipital region can be adjusted accordingly to make good contact with the scalp. Often, it was found that those O1, Oz, O3 sensors will not have a good connection with the scalp due to the amount of hair (mostly with long-haired participants) present in that region (see Figure 5). Therefore, it is essential to discuss this issue with the participant before adjusting those sensors to minimize discomfort.

Figure 5: Sensors in the occipital region circled in red. Note that not all sensors in that region are being circled.

Next, participants should be familiarized with the EEG system prior to the data collection, and proper explanations should be given to them about the EEG system. For instance, - "it is a noninvasive, harmless, painless system/procedure similar to a device that records electrical signals from the heart (which is an electrocardiogram - ECG)." Such explanations will help participants to minimize any doubts they may have prior to the study. This should be followed by showing the actual sensors to the participants (before wearing the EEG unit).

One issue anyone who comes across with this Cognionics HD-72 device might experience is how those flex sensors look like (see Figure 2 - left). Those sensors look *sharp* to anybody and might impose an idea that it could be harmful to the scalp. The participants should be given the assurance that the sensors are in fact, harmless. Explain to the participants that the flex sensors can be easily flexed (bent) and not to be deceived by its looks, and that it feels soft on the skin. This can be demonstrated by placing the flex sensors on the participants' hand. The reason that the flex sensors are developed in such a way is to prevent the sensors from just sitting on the hair (without touching the scalp) and simply to increase the chances of touching the scalp (by penetrating through the hair). The edges are blunt and do not cause any harm to the subjects. It is crucial to make sure that the participants will remain calm throughout the session without feeling any doubts about the EEG system.

The Cognionics EEG system comes with two rechargeable lithium-ion batteries (see Figure 6). On average, a fully charged battery will last well over 4-hours. The battery indicator (in the Cognionics software) will indicate the current battery status.

Figure 6: The battery

It is important to have both batteries fully charged before each experimental session. This is because it was found that during the data collection, when the battery percentage was dropped below 50%, the strength of the signal transmission (EEG waveform and event triggers transmission) gradually decreased, and the communication with the stimulus and the recording computer became unstable. Therefore, ideally, the battery should be replaced (when the capacity drops to 50%, replace it with the second battery), and the used battery should be put to charge. This will help to maintain the optimum signal strength and the data recording rate.

- *Distance Between the Two Computers*

The Cognionics EEG system utilizes two computers as with traditional wet EEG systems. Figure 7 indicates the display computer (circled right) where the stimuli are shown to the participants and the subsequent behavioral responses are recorded into the same computer. Circled left with the dotted line (most front) is the data recording computer to which the EEG waveforms and event triggers are being transmitted via the Bluetooth transmitter in the Cognionics headset.

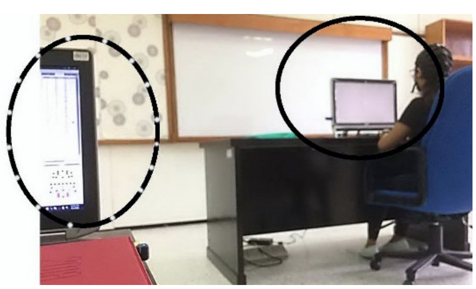

Figure 7: EEG data recording computer (circled with the dotted line), stimulus display, and the recording computer (circled with the dashed line)

The communication between the two computers is maintained via two USB dongles attached to each computer. During the study, when the participants made their responses, the corresponding trigger programmed to that response will be sent to the second computer and will be saved together with the EEG data set as a single file. To maintain the signal transmission between the two computers, ideally, the computers should not be more than 5-meters away from each other. This is to maintain the optimum Bluetooth range for data transmission. Preferably both computers should be in the same room as there is no Faraday cage involved to isolate participants to minimize any electrical interference as done with a traditional wet EEG system.

- *Tightening of the Electrodes*

Prior to the data collection, both flex and dry pad sensors should have good contact with the scalp. The contact sensitivity can be monitored in real-time via the Cognionics software (see Figure 8).

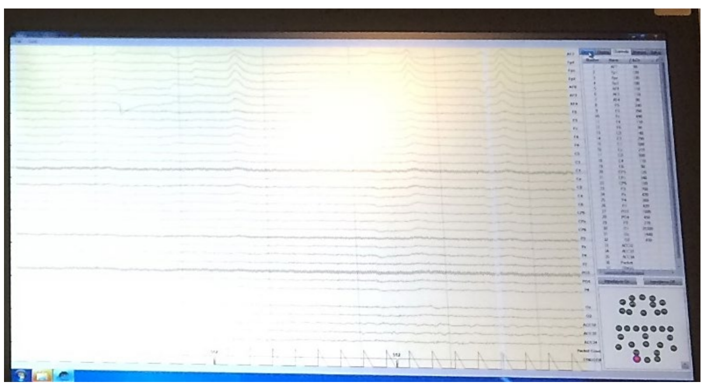

Figure 8: The Cognionics software GUI for real-time neuroimaging

If the contact strength displayed in the software remains red color, this means that there is no contact between the electrode and the scalp. Good contact will be indicated by the change in color from red to green. If the contact remains red, then the EEG straps should be tightened until the contact is made (becomes green). However, precautions must be taken not to over-tighten the straps as these electrodes can be damaged and can cause discomfort to the participant.

- *Ground and the Reference Electrodes*

In the Cognionics HD-72 EEG system, the ground and the reference electrodes are positioned in the left and right mastoid areas (see Figure 9). These electrodes are attached to the mastoid area using sticky pads (as in ECG recordings). It is vital to attach those sticky pads onto the ground and the reference electrodes before placing the EEG system onto the scalp.

Figure 9: Sticky pads (left) are used to attach to the ground and reference electrodes (right – arrow pointed to the ground electrode).

- *Tightening of the Straps*

Tightening of the electrodes should follow a series of steps. First, it is done by tightening the straps. These steps should be followed to achieve an excellent contact between the electrodes and the scalp (also see Figure 10).

Step 1: Push the circular knob (grey color) down until the lever (on the side) extends outwards. This lever, when pressed, holds the circular adjust that should be pushed forward to release the straps. This is useful when removing or putting the EEG unit on to the participant.

Step 2: Once the EEG is in place (on the scalp), rotate the circular knob clockwise to tighten the straps (anti-clockwise to release). This will automatically push the electrodes towards the scalp to make good contact.

Step 3: Repeat the procedure, starting from the frontal to the occipital region.

Step 4: Check in the GUI whether proper contact is made (indicated in color green).

Figure 10: Tightening of the electrodes. Circular knob (in grey), and the lever (small protrusion to the right) are visible.

<u>Part 2</u>

During Data Collection

- *Minimize Head Movements*

Cognionics wireless EEG system is susceptible to head and muscle movements. However, unlike in a traditional EEG system, this is reflected in real-time in the Cognionics GUI. As a result, researchers can take precautions to stabilize the EEG waves in each channel prior to the data collection (see Figure 11). This can be done by informing the participants not to make any large head and muscle movements during the data collection.

One benefit of the Cognionics system is that it is easier to show the participants what the waveforms look like with head movements (see figure 11, left), and what the researcher aims to achieve (see Figure 11, right). This step will help participants to understand the consequences (of large head movements) in real-time, which will encourage them to make an effort to stay *still* as much as possible during the data collection.

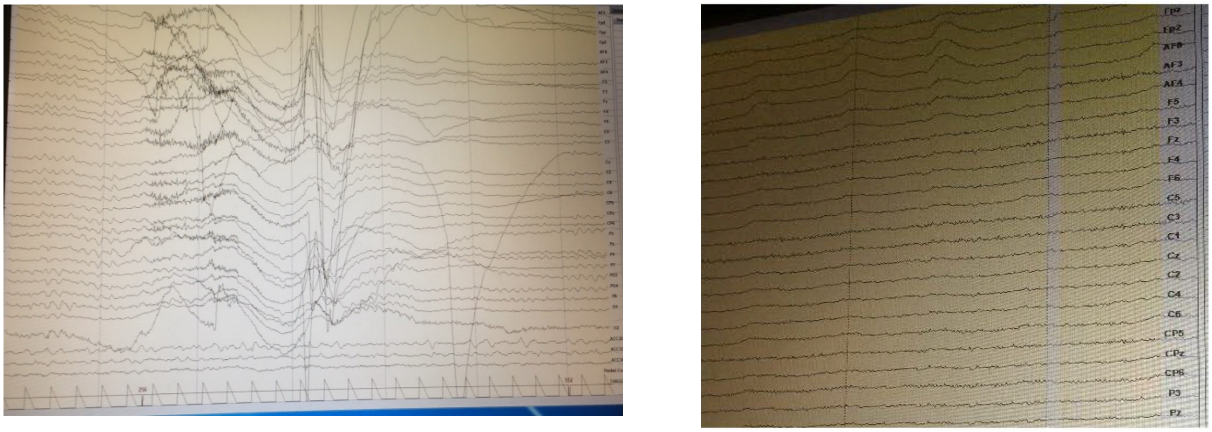

Figure 11: Head movements present (left) and when the head movements are controlled (right). See the differences in real-time in the Cognionics software.

- *No Talking*

Besides the head and muscle movements, talking during the data collection can easily contaminate the raw data. This is because the strap attached below the chin (see Figure 12) can move easily when talking, affecting the pressure points of the electrodes on the scalp. Therefore, necessary precautions must be taken to prevent jaw movements during the data collection.

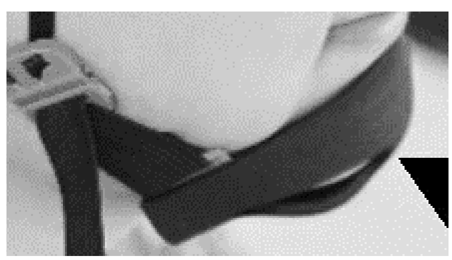

Figure 12: Chinstrap

- *Minimize Fatigue*

In cognitive neuroscience studies, fatigue is often experienced by the participants due to the repetitive nature of the experiments. Fatigue can affect participants' responses and ideally wanting to complete the experiment much sooner (Luck, 2014). To overcome the issue of fatigue, there should be adequate inter-trial intervals (ideally every 6 to 10 minutes). This will help participants to relax their postures for a while before continuing.

One advantage of the wireless EEG system is that participants can stand up and walk around the room before continuing with the trials due to its *wireless* nature. Details about intervals (break times) should be discussed with the participants prior to the data collection.

Another benefit is that due to the easy setup nature of the Cognionics system, participants are able to take toilet breaks during this time. This means that the EEG system can be easily removed (see the steps below) and then worn back to continue with the study.

Part 3

After Data Collection

- *Removal of the EEG system*

Once the data collection is completed, the final step is to remove the EEG system from the participants. It is a good practice to remove the sticky electrodes from the mastoid areas first and then place the protective plastic cover over the sticky surface to prevent the accumulation of hair, skin, or dust particles during the removal. Next, these steps should be followed:

Step 1: Rotate the circular knob anti-clockwise to release the tension of the straps. This should then be followed by pressing the levers and pushing the circular knob forward. This step should be done for every circular knob from the frontal to the occipital region. Do not attempt to push out and forward the straps without pressing the lever, as it has created a locking mechanism to prevent the movements of the straps/electrodes. Doing so can damage the straps or the electrodes, and in severe cases, can cause pain to the participants.

Step 2: Hold the edges of the straps near the mid-line and gently pull them outwards to release (expand/extend) the tension of the straps. Follow the procedure for each strap. The electrodes will then get loosened - from touching the scalp. This step is essential to minimize any damage to the electrode sensors that can occur during the removal process.

Step 3: Gently hold from the two corners in the EEG mid-line (inion and the nasion points) and gently pull the EEG unit upwards and forward to remove it from the participant’s head. This step is essential for those who have long hair and to minimize any hair tangling in the flex sensors during the removal process.

- *Cleaning*

Once the EEG system is successfully removed from the participant, the EEG system can then be prepared for the next participant or for storing.

If the system is being used for the next participant on the same day, the electrodes should be thoroughly cleaned with an anti-bacterial gel such as Purell gel (provided in the system). Cleaning should be done using the electric brush that is included in the Cognionics system. However, the anti-bacterial gel must not be directly poured onto the electrodes as this can damage the circuitry. Hence, a small amount of the anti-bacterial gel should be applied first to the electric brush. The brush should then be placed on top of the electrodes, and only then must the ON button in the electric brush be pressed. The rotating motion of the brush will clean the electrodes thoroughly.

This step should be repeated to clean all 32 electrodes by applying the gel whenever necessary. At this stage, the electrodes are not necessary to be detached from the system. However, it is ideal for replacing the sticky pads placed on the left and right mastoids (as ground and reference electrodes) for each participant. This is because the effectiveness (sensitivity) of the sensors can be reduced after a single-use. Maintaining solid ground and reference skin contact is essential to maintaining the quality of the EEG signal.

Next, if the system is ready to be stored, it is a good practice to remove the electrodes from the system to minimize any damage. After a thorough clean-up, the electrodes (flex sensors and dry pads) can be stored separately in their own provided pouch. Any used sticky pads should be discarded.

Conclusion

This paper attempted to guide researchers concerning the proper use of Cognionics HD-72 dry and mobile EEG system.

Acknowledgment:
The author would like to acknowledge Monash University, Malaysia (Neuro-business lab) and Alexandre Schaefer for granting access to the Cognionics wireless EEG system.

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