# A Practical Mobile Dry EEG System for Human Computer Interfaces

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**Abstract.** A complete mobile electroencephalogram (EEG) system based on a novel, flexible dry electrode is presented. The wireless device features 32-channels in a soft, adjustable headset. Integrated electronics enable high resolution (24-bit, 250 samples/sec) acquisition electronics and can acquire operate for more than four hours on a single AAA battery. The system weighs only 140 g and is specifically optimized for ease of use. After training users can self-don the headset in around three minutes. Test data on multiple subjects with simultaneously acquired EEGs from a traditional wet, wired system show a very high degree of signal correlation in AEP and P300 tasks.

## 1 Introduction

Portable electroencephalogram (EEG) based systems have long been explored as a tool for implementing brain- computer interfaces (BCI) [1,2,3,4]. Despite the many advancements in signal processing and algorithms towards realizing a useful system, the EEG headset itself has remained a critical barrier against a practical device. Conventional EEG systems are cumbersome, requiring extensive subject preparation. Recently, dry electrode EEG systems have been explored as an alternative. However, dry headsets still suffer from numerous issues relating to comfort (e.g., hard metal pins) and signal quality. This paper aims to present a new, wireless dry EEG headset that specifically addresses the need for a complete, mobile system and will cover both the design and experimental validation.

## 2 Sensor Design

Mobile EEG systems have focused heavily on the use of dry electrodes with mixed results. In principle, dry electrodes are attractive due to the lack of scalp preparation. In practice, they have multiple issues relating to signal quality, usability and comfort. Current dry electrodes mostly utilize the straight metal spring-pins structure [5] to push through the hair. Pin based designs introduce significant discomfort and in military or ambulatory applications, pose an injury hazard [4]. Spring loaded sensors are also too intricate and complex to produce

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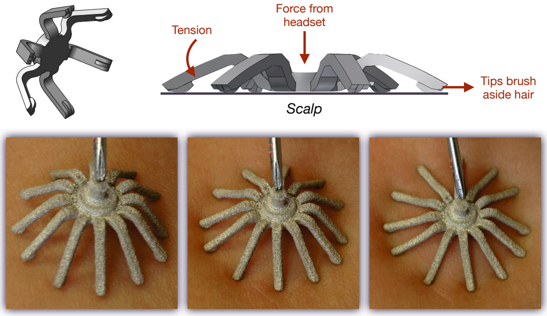


**Fig. 1.** Cognionics patent-pending flexible dry electrodes. The design consists of angled legs that can deform under pressure enabling penetration of hair without discomfort or risk of injury to the scalp.

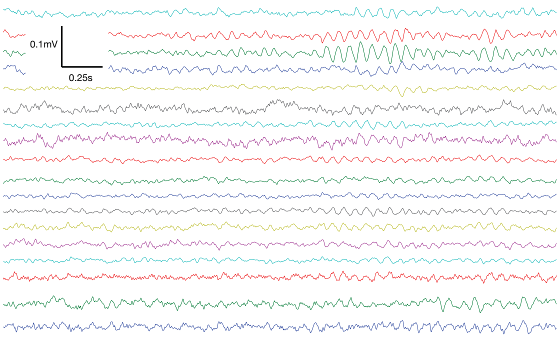


**Fig. 2.** An 18 channel raw data segment collected by the Cognionics headset using the flexible dry electrodes. The top traces clearly show alpha burst activity and demonstrates the high signal quality of the flexible dry electrode.

inexpensively. Other dry electrode designs exist, primarily based on conductive fabrics [6] or conductive brushes [7]. However, such approaches do not readily penetrate all types of hair and have issues with cost and longevity. Finally, many dry electrode systems also require significant fiddling of both the sensor and cap to generate sufficient pressure, eliminating many of their convenience advantages.

To address the performance and form-factor limitations with conventional dry EEG electrodes (e.g., hard metal pins), Cognionics, has developed a patent-pending, flexible dry electrode (Fig. 1) specifically designed to easily penetrate layers of hair while remaining safe, even under hard pressure. The new dry electrodes utilize a set of angled legs rather than straight pins. The electrode is made from a nylon material (3-D printed) that permits the legs to bend and flex outward under pressure. The flexing action helps push aside strands of hair for better scalp contact with minimal adjustment. Under hard pressure, the entire structure simply deforms and flattens to remain safe. For conductivity, the sensors are coated with metallized paint.

**Fig. 3.** Cognionics 32-channel dry EEG headset. The headset is made from soft fabric and completely encloses the wiring for the headset. The miniaturized electronics (box at the back of the head) operates from a single AAA battery and contains onboard amplification, digitization and wireless telemetry. Total system weight is only 140 g.

Under normal usage, the legs are only slightly deformed to provide for a minimal tension to ensure adequate pressure on the scalp and should not introduce any discomfort to the user. For users with different hair thicknesses, we have different sized sensors (e.g., broad legs for near-bald, thin for thick hair) to optimize hair penetration and comfort. Under most haired subjects, minimal adjustment is required to achieve sufficient scalp contact and a simple pressing motion is sufficient to part any trapped hair. The metallized legs provide for a sufficiently low impedance contact ($100-500$ k$\Omega$) to ensure low-noise EEG acquisition as shown in Figure 2.

## 3 Headset Design

We have designed a soft fabric based head harness (Fig. 3) that is adjustable to a wide variety of heads shapes and can meet the specific requirements of dry EEG systems. The headset consists of self-adjustable straps to easily conform to a variety of head sizes. After training, donning can be accomplished in less than 3 minutes without assistance. The headset is completely self-contained and contains all the necessary electronics and streams data wirelessly via Bluetooth. A very high data quality, comparable to research-grade bench systems, is made possible by 32 simultaneous 24-bit A/D converters with active electrode buffers on each channel. Typical battery life is around 5 hours of continuous streaming using a single AAA battery.

## 4 Wireless Data Acquisition Electronics

The latest advancements make it possible to construct a very high-quality portable EEG devices [4] that is far smaller than the traditional 'shelf' type systems. The electronics box for the 32-channel headset measures 2.5" x 2.5" x 0.75" and houses the amplifiers, digitizers, micro controller and wireless transceiver along with a single AAA battery for power. A summary of the system's specification is listed in Table. 1.

Evoked responses have been a mainstay for EEG-based brain computer interfaces. With wireless systems, especially ones based on conventional protocols (e.g., Bluetooth) optimized for reliable data transfer, issues with latency and jitter often prevent the accurate alignment of stimuli, event markers and EEG data.

One solution is to simply attach a physical wire to the headset for minimal latency and jitter-free transmission of event markers, as with traditional wired systems. However, such an approach defeats the purpose of a wireless headset. Cognionics has developed a novel wireless method of transmitting EEG trigger signals and event markers based on infrared and RF based custom transceivers (Fig. 4). As will be shown later, this approach permits fully wireless synchronization of EEG with external stimuli with 'wired-equivalent' performance in terms of latency and jitter. The wireless system has the additional benefit of supporting an arbitrary number of receiving headsets, enabling precision timed group experiments that were not previously possible. Finally this approach does not require the use of a custom wireless transceiver for the actual EEG data, retaining compatibility with any generic Bluetooth (or future wireless standard) device.

**Table 1.** System Specifications

| | |
|---|---|
| Channels | 32 Active plus Reference and Ground |
| Amplifier Noise | $< 1\mu V_{rms}$, 1-70 Hz |
| CMRR | >100 dB |
| ADC Resolution | 24 bits |
| Sample Rate | 250 samples/sec |
| Wireless | Bluetooth v2.1 RFCOMM |
| Trigger Latency | 300 $\mu s$ |
| Weight | 140 g, fully loaded |
| Battery | 1 AAA NiMH, 5 hours |

## 5 Testing and Validation

Testing and validating the signal from a EEG system has been a difficult endeavor. While bench tests can accurate measure the performance of the system's acquisition electronics (e.g., noise floor, CMRR), the actual performance on an actual subject is difficult to quantify due to the inherent nature of EEG signals, which are generally not repeatable, and the many variations in human head size, shape, and skin condition.

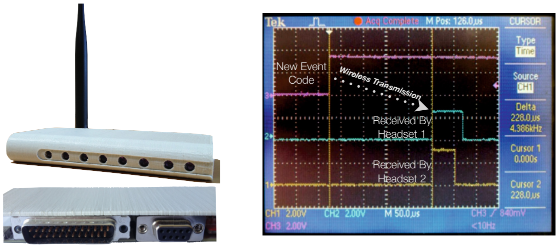


**Fig. 4.** (left) Cognionics wireless trigger transmitter. (right) Demonstration of novel wireless triggering system. Event codes received by Cognionics trigger unit are received by the wireless EEG headset with a minimal latency (<250 $\mu$s) and with virtually no jitter between different systems.

**Fig. 5.** Photograph of one subject in the test environment. The Cognionics 32-channel dry headset was placed on a subject. Standard wet adhesive electrodes, on top of abraded scalp, were placed adjacent to select dry electrodes and connected to a g.tec amplifier for simultaneous recordings.

An evoked response potential based test protocol is perhaps the best approach since evoked responses offer a repeatable signal. For a fair comparison, a simultaneous recording between wet and dry sensors is needed since conditions may change between recording sessions (e.g., subject fatigue).

For the basic validation experiment, we chose to use an AEP task along with two P300 tasks - one based on static images and another based on video. Since it is impossible to fully cap a subject with both a dry and a wet array, we selected C3-P3 and C4-P4 as the sites of interest for the comparison study.

Figure 5 shows one subject in the test environment. The dry cap was first placed on the subject. Since it is impossible to overlay a wet electrode on top of a dry electrode, the wet electrode must be placed at a location away from the dry electrode with sufficient distance to avoid gel contamination. Physical displacements are not ideal since they change the measured EEG signal. To better simulate a simultaneous wet-dry comparison, two wet electrodes were

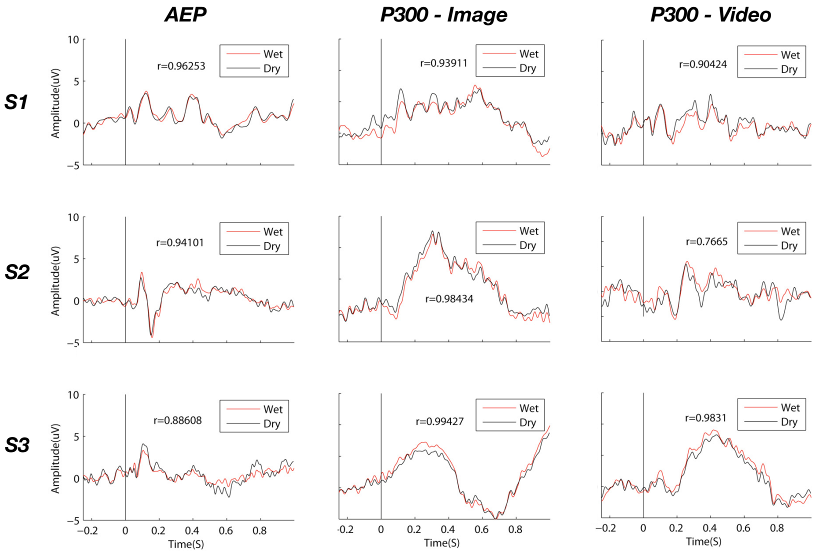


**Fig. 6.** Exemplary time averaged ERP responses from the three subject in the three tasks (AEP, P300 on still images, P300 on moving video). There is a high correlation and similarity between the signals recorded from the wireless dry system and the standard wet wired system demonstrating the quality of the flexible dry electrode and the accuracy of the wireless triggering system.

placed laterally across each of the dry electrode locations under test (C3, C4, P3, P4). Averaging the two wet electrode 'simulates' a single wet electrode on the exact same spot as the dry electrode for the best comparison. For data acquisition, a g.tec EEG device was used with the wet electrodes.

Three subjects were used for the first validation tests. Figure. 6 shows the time averaged AEP and P300 responses (bipolar C3-P3 montage). Both the wet and dry systems accurately show the expected ERP response. The lack of time shift between the wired wet and wireless dry systems also demonstrate the precision of Cognionics wireless triggering. Almost all of the tests show a high correlation (>0.9) between the wet and dry signals. In the trials with low correlation, the raw signals, as with all of the sets, show a high degree of qualitative similarity.

## 6 Conclusions

A wireless, 32-channel dry EEG system with novel dry electrodes was demonstrated and tested. The wireless EEG systems includes all of the necessary components for a complete EEG platform, including accurate triggering and event marking. The high quality of the raw signal as well as time-averaged ERP responses demonstrate the viability of the platform for constructing practical mobile brain-computer interfaces.

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