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ORIGINAL ARTICLE

Validation of the g.tec Unicorn Hybrid Black wireless EEG system

Matthew B. Pontifex | **Colt A. Coffman**

Department of Kinesiology, Michigan State University, East Lansing, Michigan, USA

Correspondence
Matthew B. Pontifex, Department of Kinesiology, 126 IM Sports Circle, Michigan State University, East Lansing, MI 48824-1049, USA.
Email: pontifex@msu.edu

Abstract

Although dry and hybrid-style electrode technology has been well validated, systems utilizing these electrodes have not been widely adopted. One reason for this may be that the systems incorporating such technology present limitations that are fundamental to the EEG approach. The g.tec Unicorn Hybrid Black system, a low density Bluetooth EEG amplifier, however, attempts to address many of these limitations to allow greater flexibility to replicate methods used with traditional EEG amplifiers and extend them to more novel applications. The aim of the present investigation was to validate the g.tec Unicorn Hybrid Black amplifier to determine if it provides comparable data to a traditional laboratory-based system when no electrode preparation is utilized or if a saline-based solution is necessary to obtain sufficient signal quality. Stimulus-locked ERPs and EEG power spectrum data were concurrently recorded using both the Unicorn Hybrid Black amplifier and a traditional high-end laboratory-based low-impedance wired system. Findings suggest that the Unicorn Hybrid Black provides valid measures for investigations of frequency spectra even with no conductive solution applied. However, to obtain valid assessments of event-related brain potentials, it appears necessary to use a conductive solution for electrode preparation. This system appears well suited to allow for high-quality and flexible EEG measures available outside of traditional laboratory environments.

KEYWORDS

dry EEG/ERP, portable EEG/ERP, wireless EEG/ERP

1 | INTRODUCTION

Technological innovations over the past several decades have resulted in substantial enhancements in the accessibility of electroencephalographic (EEG) measures. In particular, the maturation of dry and hybrid-style electrode technology—which eliminates the need for electrode gel or at the very least gives a greater range of options for the type of conductive solution utilized—has fostered considerable growth among consumer, industry, and research markets. Although such electrodes have been well validated (Heijs et al., 2021; Kam et al., 2019; Mathewson et al., 2017), the systems that employ this technology have done so in ways that have placed considerable constraints upon users—with many users having tried and subsequently shelved these devices as a result. The Unicorn

Hybrid Black system (g.tec medical engineering GmbH, Austria) represents one option in an emerging market that is making such technology more accessible by addressing many of these constraints. The Unicorn Hybrid Black system can be used as a dry or wet (gel-based) system, uses Bluetooth technology instead of a cable tethering the cap to a separate amplification system, allows for flexible placement of electrodes rather than a fixed configuration, allows for direct access to streaming data by both Matlab and Python application programming interfaces rather than being restricted to proprietary software, and falls at a price point (~$1200) that is not prohibitively expensive for application in field-based, clinical, or teaching environments. However, before such a device can be deployed, it is important to validate the extent to which this system can provide meaningful data. Accordingly, the aim of the present investigation was to validate the Unicorn Hybrid Black amplifier under different electrode preparation conditions relative to a traditional high-end laboratory-based low-impedance wired system.

Each year, an increasing number of EEG systems and companies creating EEG-related technology appear on the market. While the underlying concept of EEG remains the same, there are a number of potential constraints/limitations that occur when attempting to make this technology more accessible that are fundamental to the EEG approach. Among the most prominent criticisms of mobile/dry EEG systems is the use of arrays that only place electrodes along the forehead and generally hairless areas or use nonstandard electrode configurations that are fixed and unmodifiable. Thus, investigators must select the device that corresponds with the question of interest rather than being able to modify the array to meet their needs or in response to unique participant-related situations. Being relegated to nonstandard electrode configurations is particularly disadvantageous for being able to replicate well-established paradigms and prior laboratory-based findings. However, it is important to note that a benefit of volume conduction is that many neuroelectric potentials can still be observed despite potential nonstandard electrode configurations, as evidenced by work from Krigolson et al. (2017). Another prominent set of constraints related to bringing such devices outside of the laboratory environment is their cost and connectivity. Specifically, investigators may be less willing to deploy devices that cost tens of thousands of dollars in situations where the risk of theft or damage may be high. Although creative solutions such as utilizing recreational vehicles and travel trailers as mobile testing centers have allowed investigators to address some of these concerns, such solutions may not be uniformly appropriate or cost-effective. Similarly, the use of traditional tethered EEG systems, which run wires from the EEG cap to the amplifier, may be suboptimal or present additional constraints even when only extending to a backpack-based amplification device, ultimately limiting their use for more mobile or field-based applications.

Further, although the vast majority of systems support open source toolboxes either natively or through the collective efforts of the research community, of concern is an emerging segment of devices that use closed-system approaches that require proprietary software that fundamentally limits the ways in which the device can be used. For instance, some companies have begun adopting a subscription model that requires annual or recurring fees, meaning that investigators must continue to pay to collect new data or even just retain the ability to view or access previously collected data. While beneficial for the company, such subscription models are not only associated with potentially long-term recurring costs but may also render data inaccessible should the company go out of business creating a fundamental crisis for data integrity and validation. Other companies have implemented approaches that automatically upload, store, and potentially even process data into offsite or unsecured repositories. While appealing from a data-redundancy perspective and allowing for novel applications of more advanced processing and machine learning approaches to data, such implementations may conflict with institutional policies regarding confidentiality and security (e.g., policies that restrict the storage of data to only local or nationally hosted servers) (Hon et al., 2016). Consistent with the common criticism of EEG-related research that interpreting findings can be difficult due to the wide variation in the way measures are recorded and processed (Clayson et al., 2021), emerging options targeted toward clinical markets have implemented systems that restrict the way devices can be used so that the system/device will only work with the companies' preprogrammed assessments and only allow access to automatically processed/interpreted data rather than the raw data itself. Although there are certainly benefits associated with many of these constraints, there is a need for options within this space that remove such limitations and allow the user greater flexibility to be able to replicate methods and techniques that have been well-validated/replicated using traditional EEG approaches and extend them to more novel applications.

The Unicorn Hybrid Black system is a 24-bit amplifier that digitizes EEG activity at a sampling rate of 250 Hz from a small array (8 channels) of electrodes relative to the mastoid electrode sites. The multipin electrode configuration utilizes the g.SAHARA hybrid active electrodes (g.tec medical engineering GmbH, Austria) that allow a range of skin preparation options for dry, wet, and gel-based data collection, with electrodes connecting to the amplification system via a slide collar with a traditional fabric-based EEG cap holding the electrodes in place and allowing for modifiable placement. Data recorded from the electrodes are transmitted from a central device located at the back of the head to a computer over a Bluetooth connection, where Matlab/Python integrations enable highly flexible use of the data. For this project, an open-source Python package (https://github.com/mattpontifex/UnicornHybridBlack) was developed to continuously sample and save data from the Unicorn Hybrid Black system using a multiprocessing approach. Events are marked by polling the most recent sampling point recorded by the device and saving this information along with the event code into a separate data file. Leveraging the capabilities of PsychoPy (an open-source Python-based toolbox for administering cognitive assessments), a single computer equipped with a multi-core processor is then able to administer a computerized cognitive assessment while recording a continuous stream of EEG data that is stored locally. Accordingly, such a system—requiring only a laptop/PC and a small headset—could feasibly be deployed across a range of school, clinical, and remote settings, as well as make EEG research more accessible for special populations. As such, the aim of the present investigation was to validate the Unicorn Hybrid Black amplifier relative to a traditional high-end laboratory-based low-impedance wired system. In particular, the use of electrode gel, which requires time and skill to appropriately prepare and requires the participant to wash their hair out following testing—is suboptimal for such settings and populations; the critical question this investigation sought to answer was if the Unicorn Hybrid Black system provides comparable data to that of a traditional laboratory-based system when no electrode preparation is utilized or if a conductive solution is necessary to enhance signal quality and obtain comparable data.

2 | METHOD

2.1 | Participants

Analyses were conducted on a sample of 20 college-aged adults ($M_{age} = 23.5 \pm 0.9$ years, 14 females, 20% nonwhite) recruited from Michigan State University. All participants completed a health history and demographics questionnaire, reported being free of any neurological diseases, indicated normal or corrected-to-normal vision, and provided written informed consent in accordance with the Michigan State University Human Research Protection Program Institutional Review Board.

2.2 | Task

2.2.1 | Oddball task

During the oddball task, participants were instructed to respond as quickly and accurately as possible with a right-hand thumb press only to an infrequent target stimulus while ignoring all other stimuli (Picton, 1992; Squires et al., 1975). The target stimuli were a 5-cm-diameter white circle occurring with a probability of 22.5%, while the nontarget stimuli were a 4.8-cm-diameter dimpled white octagon occurring with a probability of 77.5%. All stimuli were presented focally on a computer monitor at a distance of 1 meter for 200 ms, with a 900 ms response window, and a 1100 ms intertrial interval using PsychoPy, 2022.1 (Peirce, 2009). A total of 360 trials were presented, resulting in 81 target stimuli. For the Neuroscan SynAmpsRT amplifier, event timing was recorded by sending a numeric code through a parallel port connecting the stimulus presentation computer to the amplifier to place the event into a dedicated channel in the EEG recording stream. The stimulus presentation computer also continuously recorded data streaming from the Unicorn Hybrid Black amplifier in a separate parallel process, allowing event timing to be recorded by polling the most recent sampling point recorded by the device and saving this information along with the event code into a separate data file.

2.2.2 | Eyes-closed task

During the eyes-closed task, participants were instructed to keep their eyes closed and their heads still until they heard an auditory tone directing them that they could reopen their eyes. The total duration of the eyes-closed period was 90 s.

2.3 | EEG recording

During completion of the tasks, EEG activity was recorded concurrently using both the Unicorn Hybrid Black amplifier (g.tec medical engineering GmbH, Austria) and a Neuroscan SynAmpsRT amplifier using a Neuroscan Quik-Cap (Compumedics, Inc., Charlotte, NC) (see Figure 1). The Unicorn Hybrid Black amplifier digitized EEG activity at a sampling rate of 250 Hz referenced to the mastoid electrode sites (M1, M2) with a resolution of 24 bits across a range of ±750 mV. A Neuroscan SynAmpsRT amplifier was used as it is representative of a traditional high-end (>$50,000 USD) laboratory-based wired EEG system. The

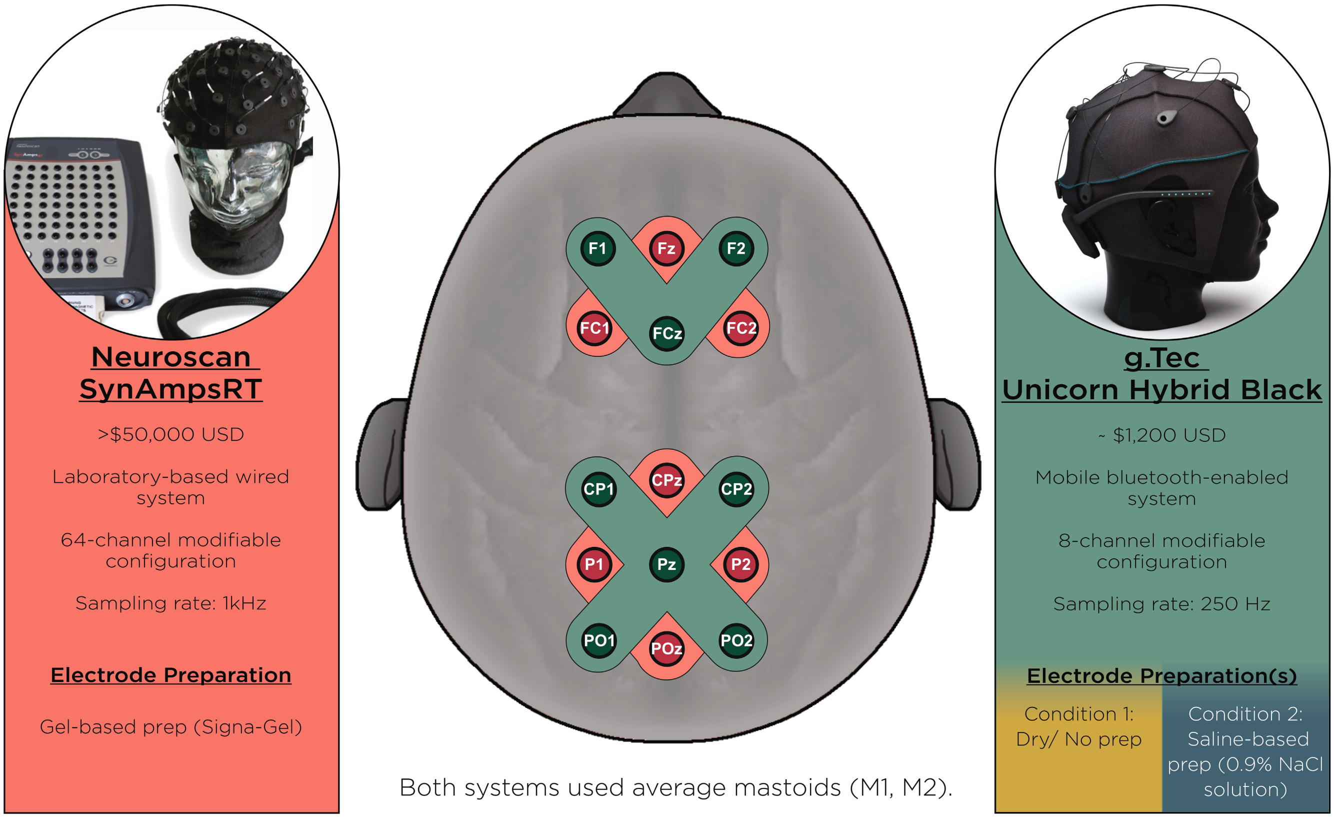

FIGURE 1 Illustration of the electrode configuration for recording from both the Unicorn Hybrid Black and SynampsRT amplifiers.

Neuroscan SynAmpsRT amplifier digitized EEG activity at a sampling rate of 1 kHz referenced to the CZ electrode site with a resolution of 24 bits across a range of ±200 mV. To ensure equivalent comparisons, the F1, F2, FCZ, CP1, CP2, PZ, PO3, and PO4 electrode sites were selected for recording using the Unicorn Hybrid Black system, with the Neuroscan SynAmpsRT amplifier using the FZ, FC1, FC2, CPZ, P1, P2, POZ, M1, and M2 electrode sites.

Following data collection, the EEG activity from both systems was imported into EEGLAB (Delorme & Makeig, 2004) using the loadcurry() and loadunicornhybridblack() functions. Data from the Neuroscan SynAmpsRT amplifier was down sampled to 250 Hz and rereferenced to the mastoid electrode sites (M1, M2) to match the recording configuration of the Unicorn Hybrid Black amplifier. Data from both systems were then filtered with a 60 Hz notch filter and bandpass filtered from 0.1 to 30 Hz using a zero-phase shift hamming windowed-sinc FIR filter. Regions of interest were then created for the frontal (Unicorn: F1, F2, FCZ; SynampsRT: FZ, FC1, FC2) and parietal (Unicorn: CP1, CP2, PZ, PO3, PO4; SynampsRT: CPZ, P1, P2, POZ) electrode sites to reflect similar topographic locations between amplifiers. For data recorded during the oddball task, stimulus-locked epochs were created for correct targets and nontargets, separately, from −100 to 1000 ms around the stimulus, and baseline corrected using the −100 to 0 ms prestimulus period. For data recorded during the eyes-closed task, epochs were created using 3000 ms intervals, and a linear detrend was applied. Artifactual segments were identified and rejected based upon voltage threshold deviations of more than 200 microvolts and point-to-point deviations of more than 100 microvolts. The data were subsequently visually inspected blind to the experimental condition and amplifier to ensure artifactual segments were removed. EEG power spectra were computed within each 3000 ms epoch of the eyes-closed task using the fast Fourier transform (FFT) algorithm with a Hanning window overlapping every 1000 ms to obtain 62 frequency bins between 0 and 30 Hz. The computation of root mean square indices of noise was obtained from the eyes-closed task prior to spectral decomposition.

Replicating the methodology of Krigolson et al. (2017), the latency and variability of the data stream recorded from the Unicorn Hybrid Black amplifier via the Bluetooth connection were assessed by sending a series of 5000 pulses from the DB25 parallel port into an active Unicorn Hybrid Black electrode and measuring the time for these pulses to be detected in the data stream. This test demonstrated a median transmission time of 21.6 ± 4.9 ms for Python to initiate the signal through the parallel port, transmit the signal from the parallel port to the Unicorn Hybrid Black, transmit the signal back from the Unicorn Hybrid

Black to the computer via Bluetooth, and convert from the Bluetooth data stream into Python. The latency and variability of the event marking approach were assessed by comparing the offset between the sampling point associated with an event and the stimulus onset identified using a photosensor connected to the participant monitor and feeding it to an active Unicorn Hybrid Black electrode. Using a sample of 1000 stimulus presentations, the median lag between the Unicorn Hybrid Black event marking the stimulus and the stimulus onset was 4.0 ± 4.0 samples (at 250 Hz sampling rate) or 16.0 ± 16.0 ms. For comparison, the median lag between the SynampsRT event marking the stimulus—transmitted via parallel port to the amplifier—and the stimulus onset identified using a photosensor connected to the participant monitor and feeding to a SynampsRT electrode was 0.0 ± 6.9 samples (at 1 kHz sampling rate), 0.0 ± 6.9 ms.

2.4 | Procedure

Using a within-subjects design, participants visited the laboratory on a single day, where they completed an informed consent form and a demographics questionnaire. Following application of the EEG cap, the electrodes connected to the Neuroscan SynAmpsRT amplifier were filled with SignaGel (Parker Laboratories, Inc., Fairfield, NJ) to ensure low-impedance—corresponding to less than ~10 kOhms impedance—recording conditions throughout the experiment. The electrodes connected to the Unicorn Hybrid Black amplifier were left without any electrode preparation other than physically manipulating the electrodes to ensure full contact with the scalp (i.e., dry preparation condition). Participants then completed an oddball task and had spectral EEG activity assessed during the eyes-closed task. This process was then repeated after saline solution was used on the electrodes connected to the Unicorn Hybrid Black amplifier. For the saline preparation condition, approximately 0.15 mL of a solution of 0.9% NaCl was applied to each of the electrodes used by the Unicorn Hybrid Black amplifier, and the electrodes were physically manipulated to ensure full contact with the scalp. Following data collection and removal of the Neuroscan Quik-Cap, electrodes were inspected to ensure that the SignaGel and saline solution stayed isolated to the electrode they were applied to and did not bridge to any other recording sites.

2.5 | Statistical analysis

A comparison of the Unicorn Hybrid Black amplifier under different electrode preparation conditions (dry preparation, saline preparation) relative to a traditional high-end laboratory-based wired system (i.e., the SynampsRT amplifier with electrodes prepared using SignaGel) was conducted in several phases corresponding to the question of interest.

First, to address the question of whether the Unicorn Hybrid Black system provides comparable results to those of a traditional laboratory-based system, analyses were conducted examining the correlation between data recorded from the Unicorn Hybrid Black amplifier under different electrode preparation conditions (dry preparation, saline preparation) relative to the data recorded from the SynampsRT amplifier. Specifically, for each electrode preparation condition, correlational analyses were conducted at the epoch level, comparing the target-locked activity from the oddball task from 0 to 1000 ms following the presentation of the target stimulus recorded from the Unicorn Hybrid Black amplifier with the concurrently recorded data from the SynampsRT amplifier. As this question is focused on whether the Unicorn Hybrid Black amplifier can suitably capture the morphological characteristics of the target-locked activity and is agnostic to particular ERP components of interest, a robust estimate of this relationship was provided by pooling the correlation across each accepted epoch and region of interest for each participant using Pearson product–moment correlation coefficients using the stats and Rmimic (Pontifex, 2020) packages in R version 4.1.2 (R Core Team, 2019). This process was repeated to examine the correlation between data recorded concurrently from each system for log power spectral activity from 0.1 Hz to 30 Hz quantified using a discrete Fourier transform for each electrode preparation condition. For both the target-locked, nontarget-locked, and spectral frequency data, analysis was conducted separately for each electrode preparation condition (dry preparation, saline preparation). Additionally, to provide a robust estimate of the internal consistency between measures, this epoch-level pooled analytic approach was replicated by computing the Cronbach's alpha for data recorded from the Unicorn Hybrid Black amplifier against concurrently recorded data from the SynampsRT amplifier using the ltm (Rizopoulos, 2006) package in R (R Core Team, 2019).

Next, to address the question of whether the Unicorn Hybrid Black system would be associated with greater noise present within the recorded data relative to that of a traditional laboratory-based system, analyses were conducted examining the root mean square (RMS) of each 3-s epoch of data recorded during the eyes-closed task under different electrode preparation conditions (dry preparation, saline preparation). Specifically, analysis was conducted comparing the RMS of the SynampsRT data against the Unicorn Hybrid Black data recorded in the dry preparation condition and the Unicorn Hybrid Black data recorded in the saline preparation condition. The analysis was conducted using a univariate multilevel model, including the random intercept for each participant, accepted epoch, and region of interest. The use of a multilevel model offers a robust way to account for several sources of participant level variability (Goldstein, 2011; Volpert-Esmond et al., 2018) and is preferable for repeated measures designs (Quené & van den Bergh, 2004). The multilevel model analysis was performed using the lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), and emmeans (Lenth et al., 2017) packages in R (R Core Team, 2019) with Kenward-Roger degrees of freedom approximations. Cohen's f^2 and d with 95% confidence intervals were computed as standardized measures of effect size, using appropriate variance corrections for within-subject (d_{rm}) comparisons (Lakens, 2013).

Additionally, replicating the methodology originally employed by Kappenman and Luck (2010) and subsequently by Mathewson et al. (2017), a permutation procedure was conducted to examine the extent to which variations in noise present in the data might impact upon the statistical power to detect differences between target and nontarget trials for the amplitude of the P3 ERP. Within each iteration of the permutation test, the target and nontarget trials were randomly sampled (with replacement) for each participant at a 1:4 ratio of target to nontarget trials. To better capture the potential impact of noise across systems and electrode preparation conditions, all trials—even those rejected as contaminated by artifacts—were made available for random sampling. The total number of target trials included was additionally iterated from 1 to 60. The sampled trials were then used to compute the mean amplitude at the PZ region of interest between 250 and 450 ms, corresponding to the P3 ERP, for target and nontarget trials. Analyses were conducted using paired samples t-test to determine if the amplitude of the target trials was statistically larger than the amplitude of the nontarget trials, using an alpha level of 0.025. This process was repeated for a total of 10,000 permutations, separately for each amplification system and electrode preparation condition.

3 | RESULTS

3.1 | Does the Unicorn hybrid black system provide comparable results to that of a traditional laboratory-based system?

As correlation is sensitive to phasic offsets, analyses were first conducted to determine if there was a systematic offset in the trigger timing between systems. This analysis examined the correlation between the concurrently recorded SynampsRT and Unicorn Hybrid Black target-locked data, shifting the Unicorn Hybrid Black data from −25 to 25 sampling points (corresponding to a potential offset of up to 100 ms prior to or following the trigger recorded by the SynampsRT). This process was done within each participant and epoch to obtain the offset corresponding to the maximal correlation. Across both dry preparation and saline preparation conditions, the best fit to the data was an offset of 4.0 ± 5.0 sampling points, which was consistent with the latency and variability of the event marking approach for the Unicorn Hybrid Black. For all subsequent analysis, the Unicorn Hybrid Black target-locked data was shifted by 4 sampling points.

3.1.1 | Dry preparation condition

Target-locked EEG activity was quantified across 61.6 ± 2.8 accepted trials, with analysis observing a moderate relationship with moderate reliability between the concurrently recorded SynampsRT and Unicorn Hybrid Black target-locked data, $r = .55$ [95% CI: 0.52 to 0.57], $p < .001$, Cronbach's alpha = 0.67 [95% CI: 0.58 to 0.73] (see Figure 2a/d). Nontarget-locked EEG activity was quantified across 265.6 ± 32.8 accepted trials, with analysis observing a moderate relationship with moderate reliability between the concurrently recorded SynampsRT and Unicorn Hybrid Black nontarget-locked data, $r = .43$ [95% CI: 0.42 to 0.45], $p < .001$, Cronbach's alpha = 0.55 [95% CI: 0.44 to 0.63] (see Figure 2b/e). Spectral EEG activity was quantified using 29.8 ± 0.2 epochs of 3 s each, with analysis observing a strong relationship with excellent reliability between the concurrently recorded SynampsRT and Unicorn Hybrid Black spectral data, $r = .84$ [95% CI: 0.82 to 0.85], $p < .001$, Cronbach's alpha = 0.91 [95% CI: 0.85 to 0.94]. (see Figure 2c/f).

3.1.2 | Saline preparation condition

Target-locked EEG activity was quantified across 63.5 ± 2.6 accepted trials, with analysis observing a strong relationship with high reliability between the concurrently recorded SynampsRT and Unicorn Hybrid Black target-locked data, $r = .78$ [95% CI: 0.76 to 0.79], $p < .001$, Cronbach's alpha = 0.86 [95% CI: 0.83 to 0.89] (see Figure 3a/d). Nontarget-locked EEG activity was quantified across 260.3 ± 35.5 accepted trials, with analysis observing a moderate relationship with high reliability between the concurrently recorded SynampsRT and Unicorn Hybrid Black nontarget-locked data, $r = .72$ [95% CI: 0.71 to 0.73], $p < .001$, Cronbach's alpha = 0.82

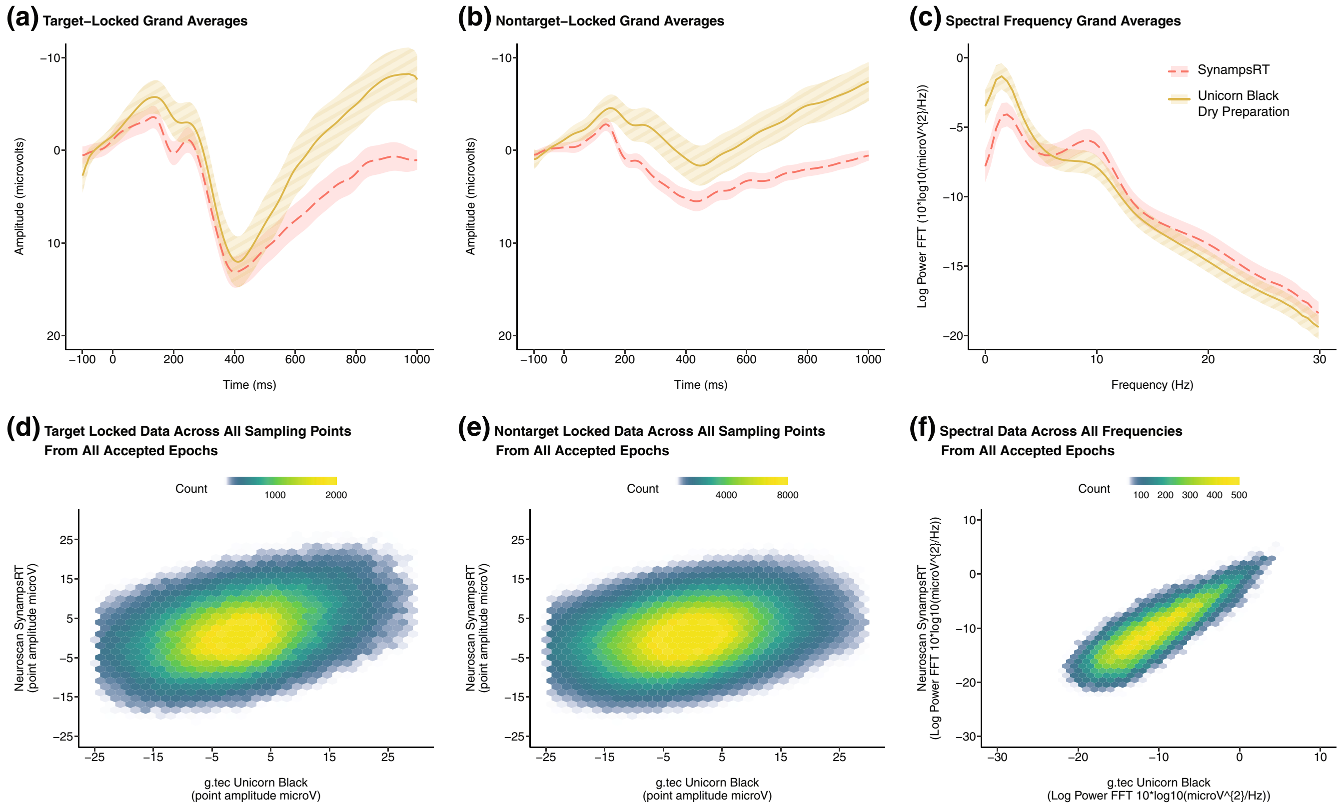

FIGURE 2 Illustration of data collected in the dry preparation condition. The top panel shows grand mean waveforms (±*SE*) for target-locked (a), nontarget-locked (b), and spectral frequency (c) data, illustrating the difference between data concurrently recorded by the Unicorn Hybrid Black and SynampsRT amplifiers. Waveforms are collapsed across accepted epochs and electrode sites. The bottom panel shows heat maps of the density of data across each participant, accepted epoch, and region of interest concurrently recorded by both the Unicorn Hybrid Black and the SynampsRT amplifiers for target-locked amplitude (d), nontarget-locked amplitude (e), and spectral frequency (f). Colorization indicates the number of samples occurring within each point on the scatterplot. Note that the electrodes used by the Neuroscan SynAmpsRT amplifier were filled with SignaGel to ensure low-impedance recording conditions throughout the experiment for all conditions; thus the notation of dry preparation refers only to the electrodes used by the Unicorn Hybrid Black.

[95% CI: 0.78 to 0.86] (see Figure 3b/e). Spectral EEG activity was quantified using 29.6 ± 0.4 epochs of 3 s each, with analysis observing a very strong relationship with excellent reliability between the concurrently recorded SynampsRT and Unicorn Hybrid Black spectral data, $r = .90$ [95% CI: 0.89 to 0.91], $p < .001$, Cronbach's alpha = 0.94 [95% CI: 0.91 to 0.97] (see Figure 3c/f).

See Figure 4 for a direct graphical comparison of non-concurrently recorded data from the Unicorn Hybrid Black from the Dry Preparation Condition with the Saline Preparation Condition.

3.2 | Is the Unicorn hybrid black system associated with greater noise than a traditional laboratory-based system?

Analysis of the relative noise of the Unicorn Hybrid Black amplifier under different electrode preparation conditions as compared to the SynampsRT amplifier revealed a main effect of the system: $F(2, 4744) = 16.7$, $p < .001$, $f^2 = 1.89$ [95% CI: 0.81 to 6.14] (see Figure 5). The dry electrode preparation condition of the Unicorn Hybrid Black was associated with the greatest noise (15.1 ± 34.7 RMS) relative to the noise recorded by the gel-prepared SynampsRT electrodes (11.7 ± 7.1 RMS), $t(\infty) = 5.4$, $p < .001$, $d_{rm} = 1.16$ [95% CI: 0.74 to 1.59]. However, even in the saline preparation condition, the Unicorn Hybrid Black was associated with elevated noise (14.0 ± 10.5 RMS) relative to the noise recorded by the gel prepared SynampsRT electrodes, $t(\infty) = 3.8$, $p < .001$, $d_{rm} = 0.5$ [95% CI: 0.24 to 0.77].

Findings from the permutation test observed that regardless of the electrode preparation, the Unicorn Hybrid Black required 8 times more trials (17 target and 68 nontarget for the dry preparation, 16 target and 64 nontarget for the saline preparation) than the SynampsRT (2 target and 8 nontarget) to achieve 80% power in detecting a difference in P3 amplitude between target and nontarget trials. To achieve over 95% power, the Unicorn Hybrid Black required over 9 times more trials (28 target and

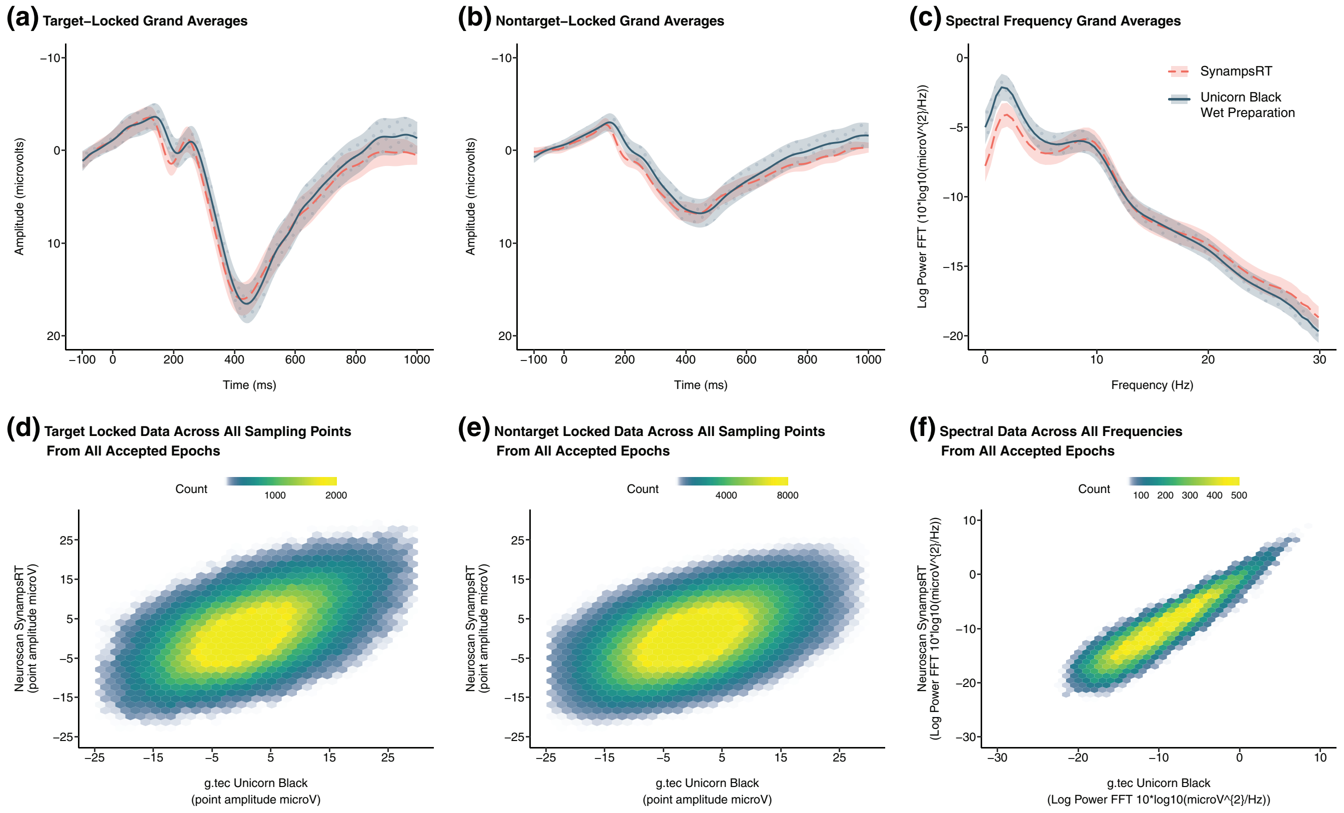

FIGURE 3 Illustration of data collected in the saline preparation condition. The top panel shows grand mean waveforms (±*SE*) for target-locked (a), nontarget-locked (b), and spectral frequency (c) data, illustrating the difference between data concurrently recorded by the Unicorn Hybrid Black and SynampsRT amplifiers. Waveforms are collapsed across accepted epochs and electrode sites. The bottom panel shows heat maps of the density of data across each participant, accepted epoch, and region of interest concurrently recorded by both the Unicorn Hybrid Black and the SynampsRT amplifiers for target-locked amplitude (d), nontarget-locked amplitude (e), and spectral frequency (f). Colorization indicates the number of samples occurring within each point on the scatterplot. Note that the electrodes used by the Neuroscan SynAmpsRT amplifier were filled with SignaGel to ensure low-impedance recording conditions throughout the experiment for all conditions; thus the notation of saline preparation refers only to the electrodes used by the Unicorn Hybrid Black.

112 nontarget for both the dry preparation and the saline preparation) than the SynampsRT (3 target and 12 nontarget).

4 | DISCUSSION

The purpose of the present investigation was to validate the Unicorn Hybrid Black system for both frequency spectra and event-locked approaches and determine the extent to which the system might provide comparable data to that of a traditional high-end, low-impedance laboratory-based system. Relative to the Neuroscan SynAmpsRT amplifier, costing over \$50,000 USD, the Unicorn Hybrid Black system, which costing around \$1200 USD, performed remarkably well. Despite the higher level of noise to be expected of electrodes sitting on the surface of the scalp without electrode gel or other conductive solution applied; the data recorded from the Unicorn Hybrid Black system exhibited moderate to strong correlations and high to excellent reliability with the data recorded from the Neuroscan SynAmpsRT amplifier. In particular, frequency spectra during the dry preparation condition were well characterized with a correlation of 0.84 and Cronbach's alpha of 0.91, suggesting the utility of this system for applications where spectral EEG characteristics are of interest but additional EEG preparation time is not available.

Although event-locked data recorded from the Unicorn Hybrid Black system during the dry preparation condition exhibited weaker relationships with the data recorded from the Neuroscan SynAmpsRT amplifier, permutation testing suggests that the additional noise in the data could be overcome by increasing the number of trials. Specifically, sufficient power was obtained by increasing the number of target trials. Such a finding generally mirrors that of Mathewson et al. (2017), who observed that active-dry electrodes required a fivefold increase in the number of target trials. In practice, despite the increased noise and artifact present within the data recorded from

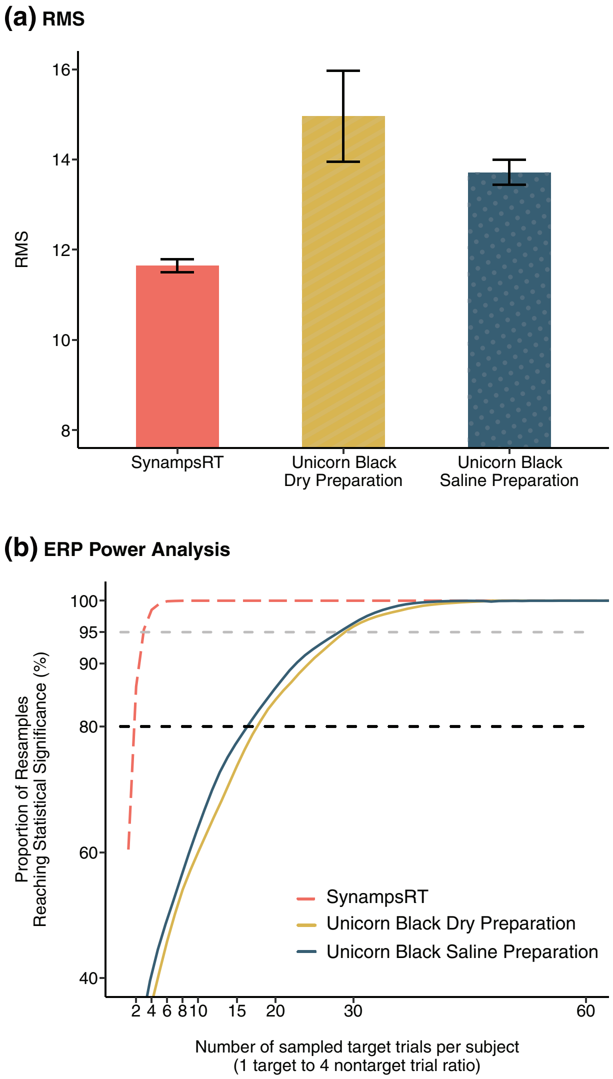

FIGURE 4 Illustration of the root mean square (±*SE*) for each amplification system and electrode preparation condition (a) collapsed across each region of interest and epoch of data recorded during the eyes-closed task. Note that each epoch was 3 s in duration. The results of the ERP power analysis (b) illustrate the proportions of the 10,000 permutations for each number of target trials that achieved statistical significance in detecting a difference in P3 amplitude between target and nontarget trials for each amplification system and electrode preparation condition. To better capture the potential impact of noise across systems and electrode preparation conditions, all trials—even those rejected as contaminated by artifact—were made available in the permutation process.

the Unicorn Hybrid Black system; following the Cohen and Polich (1997) guidelines recommended for stability of the P3 ERP component appears to be sufficient to detect differences between target and nontarget trials with 95% power. Collectively, given the moderate correlation and increased number of trials required, our interpretation of the present findings is that, although it is feasible to obtain event-locked data using such a device without electrode preparation, caution is warranted in the experimental design and interpretation of the resultant data. However, for demonstrations, outreach programs, and pilot-project related applications when it may not be feasible to prepare electrodes with conductive solution; the Unicorn Hybrid Black system with dry electrode preparation appears well suited at obtaining data that is moderately well correlated and moderately reliable with what might be obtained in a traditional EEG recording situation.

Despite providing reasonable data even without electrode preparation, the application of a small amount of saline solution to the Unicorn Hybrid Black electrodes markedly improved the signal quality and reduced the residual noise to a level close to that of the electro-gel-prepared Neuroscan SynAmpsRT electrodes. Frequency spectra were exceptionally well characterized with a correlation of 0.9 and Cronbach's alpha of 0.94 between data recorded from the Unicorn Hybrid Black and the Neuroscan SynAmpsRT. In particular, the addition of the saline solution allowed the system to better capture low-frequency (<10 Hz) spectral activity. However, the addition of the saline solution most prominently improved the signal quality of the event-locked data, with data recorded by the Unicorn Hybrid Black strongly correlating and providing high reliability to that which was recorded by the Neuroscan SynAmpsRT. Given the strong association, high reliability, and relatively consistent offset in the trigger timing, the increase in the number of trials required to achieve appropriate power in detecting differences between target and nontarget trials remains consistent with extant guidelines; our interpretation of the present findings is that the Unicorn Hybrid Black with electrodes prepared using a conductive solution provides a valid means of assessing event-related potentials.

Despite the relative strength of the present investigation, which concurrently recorded from both the Unicorn Hybrid Black and Neuroscan SynAmpsRT systems, it is important to acknowledge the limitations of the present investigation. In particular, the nature of the concurrent recording approach required the use of a desktop PC tower to enable sending triggers to the Neuroscan SynAmpsRT via the parallel port. Thus, while it is not a far stretch to discuss the utility of the Unicorn Hybrid Black system for implementing EEG measures using only a laptop and the cap, the extent to which a laptop can manage the multiprocessing implementation of the Unicorn Hybrid Black Python API without dropped samples or potential delays in trigger timing would be dependent upon the hardware. However, sampling the Unicorn Hybrid Black 250 times per second and logging the data as a background process on a separate thread/core represents a relatively light workload for the powerful multicore processors that are now ubiquitous, even within inexpensive laptops. It is

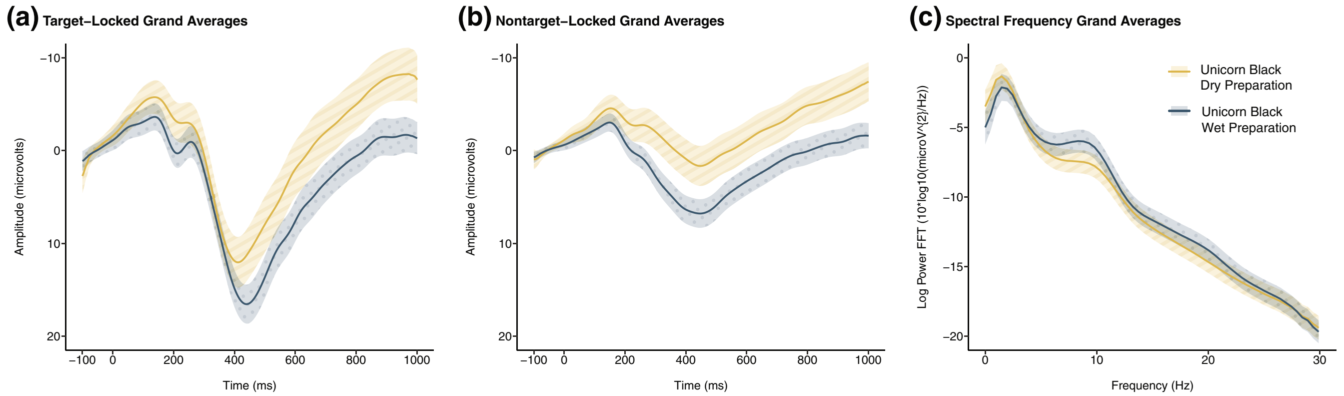

FIGURE 5 Illustration of data collected from the Unicorn Hybrid Black contrasting the dry preparation condition against the saline preparation condition. The top panel shows grand mean waveforms (±*SE*) for target-locked (a), nontarget-locked (b), and spectral frequency (c) data collapsed across accepted epochs and electrode sites. Note that the data from the dry preparation condition was not concurrently recorded with the data from the saline preparation condition.

also important to acknowledge the criticism of the small number of electrodes that are used by the Unicorn Hybrid Black. Indeed, 8 channels represent a particularly small array in contrast to other dry or mobile EEG systems that offer electrode arrays with a greater number of channels. Thus, while the Unicorn Hybrid Black addresses many prominent limitations of these other systems, the small number of available channels may not be ideal for certain applications.

Collectively, findings from the present investigation suggest that the Unicorn Hybrid Black provides valid measures for investigations of frequency spectra even with no conductive solution applied. However, the use of a conductive solution for electrode preparation is preferable for valid assessments of event-related brain potentials. Accordingly, this device—as well as other similarly capable systems in this emerging market—fills a particular niche with regard to making high-quality and flexible EEG measures available outside traditional laboratory environments. In particular, despite growing efforts at enhancing undergraduate and preundergraduate opportunities for instruction and research using electrophysiological measures—such as the Preparing Undergraduates for Research in STEM Using Electrophysiology (PURSUE) initiative—the expense of equipment is a strong limiting factor, followed closely by (1) time/skill requirements for electrode preparation and (2) the need to wash electrode gel from the hair. The Unicorn Hybrid Black would seem to address each of these issues while also being sufficiently inexpensive that even predominately undergraduate serving institutions could afford it. Beyond such applications, as a valid means of obtaining high-quality EEG measures, the mobility of the device offers a number of future opportunities to examine more real-world applications and context, as well as integrate well-established psychophysiological measures into areas, projects, and even populations where coming into a laboratory or using a traditional wet-EEG approach is prohibitive.

AUTHOR CONTRIBUTIONS

Matthew B. Pontifex: Conceptualization; formal analysis; methodology; project administration; resources; software; supervision; validation; visualization; writing – original draft; writing – review and editing. **Colt A. Coffman:** Data curation; investigation; writing – original draft; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

No conflicting financial interests exist. Neither the manufacturer of the g.tec Unicorn Hybrid Black or the Neuroscan SynampsRT amplification systems were involved in or aware of the design, conduct, and analysis of the present investigation. No discounts or subsidies were provided for the purchase of equipment, supplies, or salary support for this investigation.

M. B. Pontifex maintains the EEGLAB plugin for reading in the EEG data recorded by the SynampsRT system (https://github.com/mattpontifex/loadcurry). M. B. Pontifex also wrote a Python package (https://github.com/mattpontifex/UnicornHybridBlack) that integrates stimulus presentation using PsychoPy with the g.tec Python API to enable continuous sampling of the Unicorn Hybrid Black with event triggers and the EEGLAB plugin for reading in the data from this package. No authors were involved in the development or maintenance of the g.tec Python API or the PsychoPy stimulus presentation software.

DATA AVAILABILITY STATEMENT

The data and associated documentation will be made available under a data-sharing agreement.

ORCID

Matthew B. Pontifex https://orcid.org/0000-0001-9819-9625
Colt A. Coffman https://orcid.org/0000-0001-8667-1638

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