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International QEEG Certification Board Guideline Minimum Technical Requirements for Performing Clinical Quantitative Electroencephalography

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Abstract

Quantitative electroencephalogram (QEEG) is a technology which has grown exponentially since the foundational publication by in Science in 1997, introducing the use of age-regressed metrics to quantify characteristics of the EEG signal, enhancing the clinical utility of EEG in neuropsychiatry. Essential to the validity and reliability of QEEG metrics is standardization of multi-channel EEG data acquisition which follows the standards set forth by the American Clinical Neurophysiology Society including accurate management of artifact and facilitation of proper visual inspection of EEG paroxysmal events both of which are expanded in this guideline. Additional requirements on the selection of EEG, quality reporting, and submission of the EEG to spectral, statistical, and topographic analysis are proposed. While there are thousands of features that can be mathematically derived using QEEG, there are common features that have been most recognized and most validated in clinical use and these along with other mathematical tools, such as low resolution electromagnetic tomographic analyses (LORETA) and classifier functions, are reviewed and cautions are noted. The efficacy of QEEG in these applications depends strongly on the quality of the acquired EEG, and the correctness of subsequent inspection, selection, and processing. These recommendations which are described in the following sections as minimum standards for the use of QEEG are supported by the International QEEG Certification Board (IQCB).

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Introduction

Quantitative electroencephalography (QEEG) is a widely established technology since its introduction in 1977 by John and colleagues.[1] This guideline follows the standards of the American Clinical Neurophysiology Society (ACNS)[2] and serves as an extension of Sinha et al,[3] entitled, *American Clinical Neurophysiology Society Guideline 1: Minimum Technical Requirements for Performing Clinical Electroencephalography* ("The EEG Guideline") and adopts those requirements as detailed (modified or augmented) below, as a requirement for the acquisition of multi-channel electroencephalogram (EEG) suitable for QEEG analysis. The current guideline further places additional requirements on the selection of EEG, quality reporting, and submission of the EEG to spectral, statistical, and topographic analysis.

The purpose of this guideline is to specify the minimum alterations/adaptations, and additional necessary processing steps required to obtain standardized QEEG results for purposes of reporting, planning of treatment, and assessment of progress, as well as for forensic and insurance purposes. The main intent of this guideline, endorsed by the International QEEG Certification Board (IQCB), is to provide guidelines for EEG/QEEG submissions to the IQCB for purposes of obtaining practicum and mentoring credit toward certification. It is also intended as an educational resource when teaching proper QEEG practices. As a general standard, it is intended that conformance to this guideline would provide suitable evidence to refute challenges to QEEG data used in forensic or research settings. While it is not considered a requirement for all QEEG work, it sets a standard for intakes and baselines, and for data intended for comparative studies. It does not preclude the use of short recordings, in appropriate clinical settings. However, any such ad-hoc recordings could not be said to comply with the IQCB guidelines.

These guidelines were constructed from a systematic review of relevant literature, focusing on issues of recording quality and clinical use, as represented by the literature cited and provided in the Supplemental Bibliography. They were refined by a collaborative process of discussions and summarization walking through an optimal procedure and focusing on practical issues, by the members of the IQCB with extensive experience, expertise, and relevant prior publications. Consensus recommendations were mutually agreed upon and incorporated into the present document. They address concerns that may arise when EEG or QEEG data acquisition, artifacting, or results are questioned. Compliance with these guidelines will help to ensure uniformity and reliability.

As a supplement to conventional EEG, QEEG and neurometrics have clinical utility in areas including:

1. Early detection of disease, dysfunction, or developmental problems
2. Quantitative assessment of brain functional abnormalities
3. Tracking of changes in degree of abnormality over time
4. Computer-assisted differential diagnosis of various disorders
5. Differentiating between normal and abnormal EEG with regard to background activity
6. Prediction of treatment response
7. Monitoring of treatment outcomes

The efficacy of QEEG in these and other applications depends strongly on the quality of the acquired EEG and the correctness of subsequent inspection, selection, and processing, as described in the following sections: Acquisition, Visual Inspection, Selection and Artifact Rejection, Computation of Metrics, LORETA, ICA and PCA, and Discriminants and Classification Algorithms. These sections define a sequence of considerations and processes that are intended to ensure a uniform measure of compliance for EEG for QEEG review.

Acquisition

The basic EEG recording should include the 19 locations of the International 10-20 system of electrode placement at a minimum as specified by Acharya et al.[4,5] The Sinha[3] EEG guideline specifies 10 min each of eyes-open (EO) and eyes-closed (EC) of EEG with minimal amounts of artifact present, for a total of 20 min of recorded EEG. However, the "minimal artifact" standard for EEG review allows greater inclusion of observed artifacts than the standard for "artifact-free QEEG". For instance, eyeblinks and other eye movement activity, especially during the EO recording, are expected in an EEG regardless of the length of the recording. Such activity, as well as muscle or movement "artifact," can be read by the EEG reviewer to help determine the subjective and behavioral state of the client. Also, the presence of a drowsiness condition such as alpha dropout, invasive vertex events, or sleep onset, are also of clinical relevance, and should become part of the EEG report. In contrast, when selecting "artifact-free" EEG for QEEG, all eyeblinks, eye movement, muscle, or other sporadic physiological or environmental artifact must be removed, generally by "deselection" or "snipping" such regions from the recording. It may be preferable to record EO before EC, to avoid drowsiness when the EC recording

precedes the EO recording. EC could also be recorded first, to make it easier for the subject to stay awake with EO.

The EEG Guideline states that additional time beyond the initial 20 min may be necessary to include sufficient photic activation and hyperventilation. For most clinical applications, it is acceptable to forego photic activation and hyperventilation, as these tests are more oriented toward epileptiform responses in a routine neurological application. They are intended to provoke intermittent activity, which is contrary to the intent of QEEG which is to evaluate the resting background resting state. Moreover, only a medically qualified practitioner should employ photic or hyperventilation methods. Ten minutes of EC and ten minutes of EO are typically sufficient to harvest the recommended 2 to 5 min of "clean" EEG for a QEEG process.

Visual Inspection

The entire EEG should then be reviewed by a qualified EEG reviewer, who is competent to discern between medically significant findings and normal, or artifacted EEG. Board certification by the International Quantitative EEG Certification Board (IQCB) or equivalent, plus sufficient experience to support a suitable level of competence, are required when performing this phase. Using unfiltered or filtered EEG in multiple montages, the EEG traces should be inspected for overall quality, and for the presence of notable abnormalities or other clinically relevant deviations. The purpose of this review is to determine whether the EEG has sufficient quality and quantity to be used for QEEG analysis, and to identify any clinical indications that may be present. Obvious problems such as loose electrodes, cable sway, electrode pops, bad EEG channels, reference contamination, or excess environmental noise should be noted, as they adversely affect the QEEG. While an experienced EEG reviewer may be able to "read through" noise or other artifacts, the QEEG is unforgiving and can produce highly misleading results when applied to noisy data.

The purpose of the quality review is to ensure that the EEG samples submitted for quantitative analysis are not compromised by basic EEG quality concerns. This review should be consistent with Tatum's ACNS Guidelines for EEG Reporting.[6] It is sufficient for the EEG reviewer to be certain that significant abnormalities would be visually detected, and that an appropriate medical referral for a clinical EEG would be recommended if there is any concern. Even a reviewer who cannot definitively identify a particular abnormality should be able to recognize that it has a morphology and distribution that calls for an outside referral. Significant neurological concerns such as encephalopathy, epilepsy, concussion, or toxemia may become evident at this phase and have significance for the clinical outcome. When evident, they should be noted, and clinical correlation recommended. When a serious neurological issue is evident or suspected, further review should be done, ideally by a qualified, certified medical professional, neurologist in clinical neurophysiology, sleep, epilepsy, or other related specialties.

The initial visual inspection should address observations including background rhythms, dominant rhythms, diffuse excesses or deficits, alpha presence and blocking, alpha being organized or disorganized, paroxysms or epileptiform abnormalities, asymmetries, focal deviations, or visible phenotypes such as focal or diffuse excesses. Vertex events of various types should be noted, as they may indicate onset of drowsiness, epileptiform abnormalities, sleep disturbance, or other, possibly benign, variants. It is recommended to go into the QEEG analysis with full awareness of the patient/client clinical background and associated characteristics of the EEG signals, to ensure sound interpretation of QEEG results. For example, client history may be relevant to put into context state changes or intermittent discharges commonly associated with more than one specific disorder.

There are numerous possible observations that may not be notable on a routine visual inspection of the EEG, but relevant to QEEG results. For example, theta elevated but within "normal" limits, temporal alpha, excess beta activity not attributable to a neurological disorder, or slight deviations from standard forms of posterior dominant rhythm (eg, symmetry; characteristic waxing and waning; sinusoids; blocking with eyes open; and maximal posterior rhythm, typically between 8 and 12 Hz) may appear. They might not be noted in a routine EEG but will show up in QEEG tables and maps, and can be relevant to the mental health-related issues, if not overt neurological abnormalities. The EEG reviewer should note motion, muscle, and eye-related artifacts, with possible comment on the representation of the client's state of mind, or physical behavior (agitation, irritability, restlessness, sleepiness, distractedness, etc). The presence of drowsiness does not disqualify the EEG for routine use as long as deviations from an awake state are documented. It may be useful to coach a subject back to wakefulness if the intent of the EEG is to acquire an alert EEG.

Visual inspection may also identify significant neurological concerns, such as diffuse or focal slowing, or epileptiform activity, which may occur in Autism Spectrum Disorders (ASD), attention deficit hyperactivity disorder (ADHD) and other neuropathic or developmental disorders besides epilepsy (Swatzyna, et al,[7] Swatznya, et al[8]). Most intermittent epileptiform activity will likely be averaged out in the artifacting process, making visual inspection for such attributes essential.

Caution must be taken when interpreting Fast Fourier Transformed (FFT)-based power maps, to ensure that there are no EEG features that may compromise the validity of the maps. Even without database comparisons, the nature of the FFT is to obscure feature morphology and time-behavior, by reducing the EEG to a set of sinusoids and their related metrics. For example, a wicket-shaped morphology can produce the appearance of harmonics that can be misinterpreted as excess fast activity.

In summary, notable EEG findings can be classified into three basic groups: "rule out," "throw out," and "refer out." "Rule out" means that an observation may be related to a significant finding such as diffuse slowing, focal abnormalities,

notable asymmetries, and other aspects that suggest or support a possible disorder, within the scope of practice and competence of the EEG reviewer. "Throw out" refers to EEG segments that contain sources of physiological and environmental artifact such as eye blinks, line interference, cable sway, movement, and other artifacts that must be removed for useful QEEG results. "Refer out" points to a finding that may indicate a suspected neurological disorder or neuropathy that calls for a clinical medical referral. A "refer out" finding may be outside the scope of practice and competence of the EEG reviewer. Keeping these categories distinct and clear is essential to classifying the EEG findings in preparation for QEEG analysis.

The following is a possible outline for the visual quality review report:

1. Overall quality of the EEG: (good / marginal /poor)
2. Presence of Artifact: (none / mild / moderate / severe)
3. Amount of artifact free portions for quantitative analysis: (adequate / inadequate)
4. Background rhythm: (describe background and also alpha observations)
5. Drowsiness/sleep (describe if present)
6. Presence of paroxysmal disturbances: (describe if present)
7. Comments: (describe abnormalities noted, possible significance, possible issues with QEEG, recommended clinical correlation if any)

Selection and Artifact Rejection

After a sufficient visual inspection of the EEG, it is necessary to select epochs for subsequent processing. In this step, any possible artifact that will affect the QEEG analysis is removed.[9] The EEG submitted for QEEG processing must be uniformly free of physiological or environmental contamination, so that the resulting EEG contains primarily electrocortical activity. Contamination includes eye blinks, eye rolls, lateral eye movements, muscle twitches, cable sway, electrode pops, 50 or 60 Hz interference, etc Artifacts may be removed from the digital recording using a principal component analysis (PCA[10,11]), producing a new, shorter EEG, that does not contain any of the offending signals. This method, principal component analysis (PCA) removes all channels for the selected section, reducing the amount of data available. An alternative approach based on independent component analysis(ICA) can be applied with appropriate caution as described below. It is recommended that there be a total of 2 to 5 min of artifact-free EEG data for submission to QEEG analysis, and that no segment be less than 1 s in length. ICA-based methods can preserve good data from all channels for the entire time, while removing artifactual estimated dipole sources.

When removing the aforementioned artifacts, it is important to not exclude clinically significant EEG transients, whether normal or abnormal, that will be reflected appropriately in the QEEG. This includes frontal intermittent rhythmic delta activity (FIRDA), occipital intermittent rhythmic delta activity (OIRDA) frontal intermittent rhythmic theta activity (FIRTA), posterior slow waves of youth (PSWy), etc Because these abnormal rhythms are true EEG signals, they belong in the EEG that is being analyzed, so that the QEEG will correctly show a significant excess of this activity if present. Thus, the EEG becomes a valid assessment of the client's brain condition, with the capacity to analyze predictive discriminants, track progression of a particular condition, or suggest possible remediation of a condition.

Automated artifact detection methods have been shown to be reliable in assisting in the removal of typical artifacts such as eye, muscle, and motion, when used correctly. Computational methods can work effectively using sufficiently representative "training" samples of initial EEG. The selected training sample, or template, should avoid bias, making sure that a full range of background rhythms and normal variation in the EEG are included. This will ensure that both the rejection algorithm will not exclude perfectly good EEG, and also that the result is not many small segments of disjointed EEG. A large number (more than 10) of small EEG segments (on the order of 1 s in length) will produce QEEG results of questionable validity.

There are also auto-artifacting methods that train themselves on a segment of user-selected EEG and proceed to reject artifacts according to amplitude or time-based criteria. When used, visual inspection should be used to vet the results of computational processing and ensure that (1) normal EEG activity is not being erroneously rejected, and (2) segments of true artifact are not being missed. A brief visual inspection of the artifacted results can be sufficient to confirm that the automated method is behaving as expected and is not over-artifacting or under-artifacting segments. However, over-reliance on automated artifacting and a failure to inspect the total recording can lead an EEG reviewer toward laziness or carelessness that can have adverse results.

The selected "clean" EEG submitted for QEEG analysis should be at a minimum 1 min in length, but ideally should be 2 to 5 min in length. This minimum length is necessitated by the need to measure a sufficiently representative sample of the background EEG including variable bursts that may be up to 10 or more seconds in length. The maximum length is necessitated by the need to avoid time-related state changes in cognitive state within the EEG, which may not have been anticipated in the construction of the QEEG database. QEEG databases are generally based upon samples in the range of 2 to 5 min; similar data samples should be submitted for automated analysis. In extreme cases of hyperactivity or agitation, it may be necessary to acquire up to 30 min or more of EEG in order to harvest 2 min of clean signal.

Unless the purpose of the EEG is to measure vigilance changes for a sleep study or to detect primary disorders of vigilance, drowsy segments should not be submitted to QEEG analysis, as they do not meet the criteria for valid analysis in the wakeful resting state EEG. It is acceptable to submit only 1-2 min of the recording in cases of labile vigilance or sleep states, while avoiding the earliest or the latest portions of the

recording. For example, use of the first minute of data has been reported to reduce the accuracy of discriminant functions, when compared to the second minute of data.[10] It should also be judged whether other EEG segments should be excluded, such as areas of paroxysmal events, or extreme state shifts.

The fundamental spectral analysis for a standard QEEG should use FFT or an equivalent method. The FFT algorithm requires the selection of an epoch size, which determines the fundamental frequency sensitivity of the analysis. For example, a 1 s epoch will produce 1 Hz "bins" in the FFT. A 2 s epoch would produce 0.5 Hz bins.

Computation of Metrics

The FFT analysis is used to construct estimates of spectral power in predefined frequency bands. These bands should be defined in a manner consistent with the published standards of the ACNS[2–4,6,10,12–14] and related sources.[15–18] At a minimum, QEEG analysis should incorporate recognized band definitions for delta, theta, alpha (possibly low and high alpha), and several bands of low beta, sensorimotor rhythm (SMR), beta, high beta, gamma, etc Amplifier amplitude matching should be applied when constructing analysis for comparison between different systems.[19] Further, the actual broad band cutoffs may vary in post-acquisition in order to match appropriate broad band definitions used by different available normative or clinical referenced databases.

When standardized methods are applied to QEEG acquisition and analysis, uniformity can be expected, which has been documented in studies comparing different acquisition devices and QEEG software across various populations.[18–22] This means that at the level of the basic QEEG metrics, it is possible to define processes and methods that lead to a consistent and repeatable result across different systems and environments, supported by published reports.

QEEG metrics are derived primarily from the FFT analysis, and postprocessing thereof. Some of the basic metrics have well defined and documented methods for calculation. These include absolute power, relative power, and symmetry.[23–28] The standard QEEG report should include these metrics in tabular and surface topographic map form at a minimum.

The user is advised to review the research design and statistics that have been employed in the creation of the database being used to determine statistical deviations from normal for age. The database should have met the rigor of statistical validity and reliability for its metrics, and the authors should have published, preferably in peer-reviewed publications or review panels (eg US FDA). Findings should address the contribution of factors such as gender, race, culture, socio-economic status, medications, current diagnoses, or other imaging data. These should have been examined and considered to reveal any significant statistical influence on these metrics. Several of the currently available normative referenced databases that have met FDA 510(K) approval have demonstrated that QEEG metrics are robust across race and culture with no significant variance due to such factors. There are databases that separate gender differences; however, this segregation does not invalidate the use of combined gender in a database as described by the authors in much the same way that diurnal effects are taken into consideration by including a range of recording times (eg morning, afternoon) to account for such variance. For published references for database reliability, please refer to Kaiser & Sterman[25] Ahn, et al[26]; Lorensen & Dickson[27]; Johnstone, Gunkelman, & Sinha[28]; Thatcher, North, & Biver[29]; Thatcher, Walker, & Biver[30]; Gunstad, et al[31] For an historical depiction, refer to Thatcher, & Lubar.[32]

Low Resolution Electromagnetic Tomography

There is a set of algorithms that has been established to effectively compute the inverse solution for the EEG surface cortical data, producing a current source density (CSD) estimate of the brain activity and localization. These have existed for several decades and have been validated in studies including correlation with conventional imaging, and event-related potential recordings. The list of such methods includes VARETA, bcVARETA, LORETA, sLORETA, eLORETA, swLORETA, and emerging implementations. All these methods use the same theoretical foundation, providing a statistically-derived estimate of the most likely underlying sources of the scalp-recorded EEG.[33–36]

ICA and PCA

Independent Component Analysis (ICA) and Principal Component Analysis (PCA) are complex recursive methods that attempt to decompose the EEG signal into a set of dipole sources based on their contribution to the total EEG signal. They are useful in removing volume-conducted sources such as eye blinks and eye movement and in identifying important brain dipole sources. These are in general use, both for preprocessing EEG before inspection or analysis, and for identification of biologically meaningful sources in EEG as well as in event-related potentials (ERP's). They are useful to supplement visual inspection and should also be used if the comparative database uses similar methods to clean the EEG.

If ICA is applied to EEG before submission for QEEG processing, it is important that the QEEG analysis be based on samples that have been similarly processed. When using ICA to preprocess EEG, it is important to note that human judgment, experience, and knowledge of EEG fundamentals (or artificial intelligence) are necessary to determine if any component is "real" EEG, or if it is artifact, and should be discarded. This places a level of uncertainty in the use of ICA processing and compels the user to vet the ICA results with visual findings before proceeding with QEEG higher-order statistical analysis in the same manner as visual inspection using any computed methods of artifact detection and eliminations is used. Also,

ICA can be taxed if very noisy EEG is submitted, and many of the 19 possible components will be expended in order to extract the noise. Overall, ICA-based methods may not have shown the uniformity that can be achieved in a more traditional FFT-based analysis using artifact clipping, and norms constructed from similarly artifacted EEG.

Discriminants and Classification Algorithms

Discriminant functions have been developed and described for populations including patients with mental illness, age-related cognitive decline, trauma, and other disorders.[37] These functions are multivariate descriptors of a distinctive profile of a disorder that optimally separates it from another group. They produce a complex derived metric based upon the fundamental QEEG metrics, combined in a manner to produce a probability that the client falls within a particular afflicted group. Discriminants have designated populations to be applied to, and rules for application. They are used to statistically confirm or rule out a suspected diagnosis, but they should not be used as a primary diagnostic screening process. In other words, they should not be used indiscriminately. Type 1 error (false positive) can occur if a discriminant is used as a screen for incoming clients. For these reasons, discriminant functions should be applied only to clients and conditions for whom there is a suspected diagnosis and to match any other exclusion criteria defined by authors of the discriminant functions.

Summary

This document has provided minimum technical requirements and a rationale for performing an assessment using quantitative EEG and quantitative methods of EEG source localization in research and clinical applications. Appendix I provides a systematic listing of the procedures outlined in this document. Appendix II provides a flow diagram showing the data and processes that are implemented. Appendix III provides a tabular comparison of the EEG and QEEG requirements, which are compared and contrasted therein. These minimum requirements have been built upon previous publications that document standards for EEG acquisition and methods of qEEG analyses including a systematic intake of relevant subject or patient medical and psychological conditions, recording standards, and basic standard metrics being used for the purposes of identifying neurophysiological functional profiles that pertain to defining a function or behavior under analysis. This document outlines important considerations that distinguish qEEG from aspects of standard clinical EEG review and interpretation and procedures to adhere in order to be consistent with current accepted methods of EEG review and clinical conditions under consideration. It is hoped that by adopting these minimum requirements and adhering to them in clinical practices and research protocols, a standardization will be firmly established allowing greater uniformity in the interpretation and sharing of information relevant to in the field of behavioral electrophysiology.

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Supplemental Material

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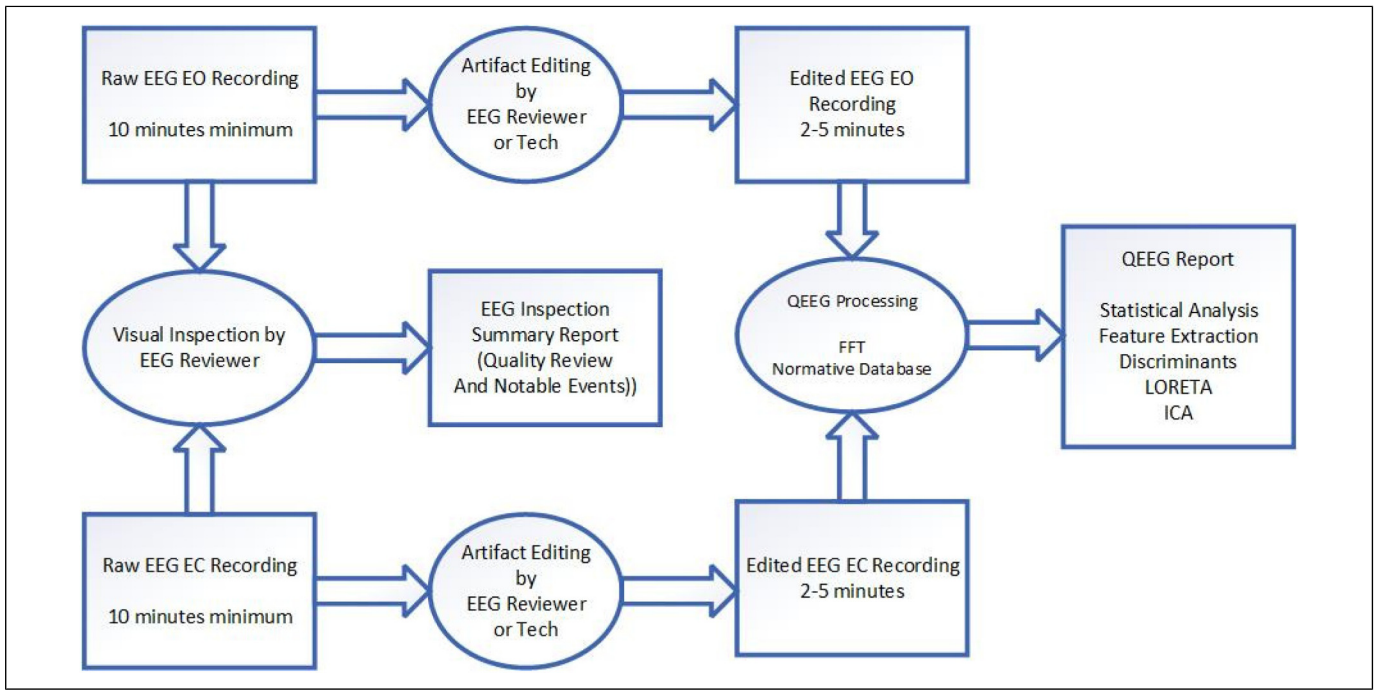
Appendix I

Recommended Procedure for EEG recording for QEEG Evaluation

1. Conduct appropriate procedures for confidentiality, informed consent, clinical history, etc.
2. Remove cellphones or other devices to another location.
3. Locate subject and equipment in an area free of interference, noise, distraction, etc.
4. Apply sensors and initiate software to observe EEG
5. Verify sensor impedance and integrity of recording
6. Allow subject to observe artifacts due to eye, mouth, etc.
7. Instruct subject how to behave during recording
8. Instruct subject to direct vision in a passive relaxed fashion with a visual fixed point
9. Record a minimum of 10 min EO while coaching and observing EEG waveforms and monitoring the subject throughout
10. Verify sensor impedance and integrity of recording
11. Instruct subject to close eyes and imagine a point in space to reduce eye movement
12. Record a minimum of 10 min EC while observing raw EEG waveforms and monitoring the subject throughout
13. Verify sensor impedance and integrity of recording
14. Visually inspect and edit EEG, using at least 3 different montages including linked ears, longitudinal bipolar, transverse, average, laplacian
15. Observe and comment on client state, drowsiness, etc including presence of EMG, EOG, etc artifact
16. Observe and comment on EEG abnormalities of possible clinical significance
17. Select 2-5 min of artifact-free EO for QEEG processing
18. Select 2-5 min of artifact-free EC for QEEG processing

Appendix II

Process and Data Flow for QEEG Evaluation



Appendix III

Table of comparison between EEG and QEEG Parameters

	EEG Visual Inspection	QEEG Analysis & Report
Record Length	Minimum of 10 min each EC and EO	2-5 min each EC and EO
Record Length Criteria	Sufficient to see artifact trends (eye, muscle, etc) rare events, and to evaluate stability of subject's state. Longer recordings are preferred for improved detection of state changes, rare paroxysms, etc.	Minimum required for statistical significance, Maximum dictated by need for a consistent sample. Longer recordings are not preferred.
Frequency Range	Guidelines require 1-70 Hz, with optional filtering	1-40 Hz typical, may go higher
Purpose	Determine quality of recording, possible artifacts, clinically notable events.	Reduce signal to a set of quantitative metrics
Eye Artifact (blinks, rolls, lateral movements)	Desired, inspected to determine state of consciousness, etc	Undesired, must be removed in some fashion
EMG Artifact	Observed in relation to arousal, tension, etc	Undesired, must be mitigated or removed in some fashion
State Shifts	Observed and commented, such as changes in arousal	Reject recording, or exclude segments from sample to be analyzed
Drowsiness	Note and comment for possible sleep issues or sleep disorder	Exclude any drowsy segments (alpha dropout, midline events) from sample to be analyzed
Paroxysmal Events	Observed and reported on	Not amenable to the QEEG analysis, generally are not reflected in quantitative results.
Use of various Montages	Yes	Yes
Additional Tasks	Optional hyperventilation, photic activation for epileptiform events	Optional reading, math, etc for cognitive loading