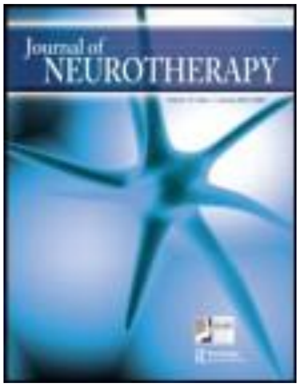

Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience

Quantitative EEG Normative Databases: A Comparative Investigation

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Published online: 07 Sep 2008.

To cite this article: Tamara D. Lorensen BSc Grad Dip & Paul Dickson BSocSc Bpsych (2003) Quantitative EEG Normative Databases: A Comparative Investigation, Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience, 7:3-4, 53-68, DOI: 10.1300/J184v07n03_03

To link to this article: http://dx.doi.org/10.1300/J184v07n03_03

Quantitative EEG Normative Databases: A Comparative Investigation

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SUMMARY. *Introduction*. No clearly defined or universally accepted standards exist which practitioners and researchers can use to determine which quantitative electroencephalographic (QEEG) database is suitable to their needs. Diverse computational and methodological approaches across QEEG databases have been vigorously defended by their respective proponents and commonly misunderstood by practitioners. The purpose of this paper is to facilitate widespread discussion from which a universal set of standards can be agreed upon and applied to QEEG databases.

Method. A broad set of criteria was developed from an extensive liter-

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The authors wish to acknowledge the contributions of M. Barry Sterman, PhD to this paper. Dr. Sterman graciously read this paper and made a number of suggestions regarding the form and the content of the paper, which were incorporated. It should be noted that Dr. Sterman is the co-author of the SKIL database, one of the databases considered in this paper.

[Co-indexing entry note]: "Quantitative EEG Normative Databases: A Comparative Investiga-tion." Lorensen, Tamara D., and Paul Dickson. Co-published simultaneously in *Journal of Neurotherapy* Vol. 7, No. 3/4, 2003, pp. 53-68; and: *Quantitative Electroencephalographic Analysis (QEEG) Databases for Neurotherapy: Description, Valida-tion, and Application* (ed: Joel F. Lubar).

10.1300/J184v07n03_03

ature review and included issues of sampling, acquisition, hardware/software, control of confounding variables, and additional issues associated with disclosure, accessibility, and the screening of potential users. These criteria were then applied to the Hudspeth, John, Sterman-Kaiser, and Thatcher databases.

Results. Results revealed reasonable concordance in data acquisition methods despite departures in inclusion/exclusion criteria and sample sizes. Significant differences were apparent in the controls used for possible confounding variables and the relative importance given to these variables.

Conclusions. Research, clinical, and ethical implications are discussed, and it is recommended that the QEEG scientific community establish peer-review procedures and processes which prevent database manufacturers from seducing peers and clinicians with technocratic information and techniques that appear to confuse the user or oversimplify the complexity and richness of QEEG applications.

KEYWORDS. Quantitative electroencephalogram, QEEG, QEEG database, normative methodology, methods, standards, controversy

INTRODUCTION

Through examination of electroencephalographic (EEG) phenomena, researchers have sought to investigate a diversity of brain related issues ranging from sleep and epilepsy to head injury and attention deficit disorder. This research has promoted the development and publication of a substantial body of literature. Historically, the literature has been based almost exclusively upon qualitative visual evaluations of the clinical EEG (Duffy, McAnulty, Jones, Als, & Albert, 1993). Researchers have used the outcomes of clinical EEG visual inspection to assist in developing working hypotheses that have aided in the formulation of more accurate diagnoses in a number of research areas (Duffy, Hughes, Miranda, Bernad, & Cook, 1994). Another objective of visual examination has been to screen the background composition of the EEG for spatial distribution of frequencies and temporal stability of various frequencies (Duffy, Jensen, Erba, Burchfiel, & Lombroso, 1984). While neurological diseases that produce focal or paroxysmal abnormal EEG stand out visibly against the background spectra, challenges have occurred in identifying various frequency compositions over time by mere visual inspection alone (Duffy, 1989).

Development of computer technology accompanied a new era of research capabilities that made it possible for investigators to examine EEG patterns using quantitative analytical methods (John, 1989; Kaiser, 2000; Sterman, 2001). The development of quantitative EEG analysis has afforded researchers the opportunity to scientifically investigate whether large samples of participants who meet medical and psychological criteria for normality also display stable, reliable and common patterns in their EEG. Similarly, other researchers also began to consider whether groups of participants with varying psychological disorders also displayed unique EEG patterns that were distinct from the EEG patterns of the non-clinical population samples. Some of the research that has compared the EEG patterns of non-clinical controls and clinical subjects, separated on the basis of either medical or psychological criteria, demonstrated that there are clear, valid and reliable distinctions in the characteristics of the EEG across groups (John, Prichep, Fridman, & Easton, 1988; John, 1989). The implication of this research is that certain EEG patterns can be common and unique to both non-clinical and clinical groups of subjects.

While John (1989) argued that there were clear benefits in using quantitative electroencephalography (QEEG) to discriminate between certain populations, Fisch and Pedley (1989) retained fervent reservations about the reliability and validity of various QEEG measures. Some of the concerns expressed were centered upon the type of instrumentation and acquisition devices used, the data reduction methods employed, and the normative databases used to compare non-clinical and clinical populations. Additional concerns have been consistently voiced about the methodological standards and related efficacy of QEEG analyses (American Psychiatric Association Task Force, 1991; Duffy et al., 1994; Oken & Chiappa, 1986; Veldhuizen, Jonkman, & Poorvliet, 1993). Kaiser (2000) suggests that as yet no adequate methodological standards appropriate to QEEG analysis have been adopted within the field. This could be a significant factor underlying any erroneous results arising from QEEG (Kaiser, 2000). According to Kaiser (2000) studies have shown that similar methodological approaches have achieved reliable outcomes based on QEEG analyses.

Likewise in a recent review by Hughes and John (1999) the authors suggested that the state of QEEG in the last decade has shown itself to remain highly reliable. Hughes and John proposed that the electrical activity of the brain is homeostatically regulated, and that this results in a predictable frequency composition of the background EEG.

In recent years, a keen interest has developed in more widespread use of the QEEG, particularly in applied clinical settings. Where QEEG technology was once the domain of established research settings and university laboratories, QEEG analysis is now available at the grass roots level in clinical settings. Consequently, the plethora of methodological issues surrounding QEEG is particularly relevant. Some practitioners, preferring to rely on QEEG data to inform certain components of their clinical practice such as evaluation and neurofeedback applications, commonly choose to select one database to meet all their clinical needs. Furthermore, there are practitioners who use additional services provided by certain databases such as discrimination, diagnosis, evaluation, interpretation and reporting of client status. Consequently, those practitioners face the added difficulty of evaluating the accuracy of these interpretations, assuming they evaluate these services at all.

This review highlights some key issues that make a compelling case for the urgent commencement of an applied and ongoing evaluation of QEEG normative databases. The major aim of this paper is to facilitate discussion and encourage ongoing appraisal of some of the current databases. This will be achieved by applying a number of criteria proposed by other authors in the field (Fisch & Pedley, 1989; John, Prichep, & Easton, 1987; Kaiser, 2000) to compare and evaluate several QEEG databases. These criteria will be used to draw attention to methodological issues that need further disclosure or additional clarification. A likely result is the application of greater scientific rigor by both practitioners and new researchers.

METHOD

The research conducted for this paper was both inductive and exploratory. At the outset, a literature search was made for several authors who were known to have developed normative databases. Searches began with published peer-reviewed articles across a variety of journals and accessed via Queensland University Library databases. The journal searches included the *Annals of Neurology, Biological Psychiatry, Clinical Electroencephalography, Electroencephalography and Clinical Neurophysiology*, *Journal of Clinical Psychiatry*, *Journal of Neuropsychiatry and Clinical Neurosciences*, *Journal of Neurotherapy* and *Psychiatry Research*.

Where the data were unavailable from these sources, electronic on-line searches for authors, subjects, and commercial normative databases were conducted using internet search engines. The normative databases examined were John (NxLink, 2001); Hudspeth (Hudspeth, 1999); Sterman-Kaiser (Sterman-Kaiser Imaging Laboratory, 2000) and Thatcher (Thatcher, Biver, Walker, North, & Curtin, 2000). The John database is particularly large and this proved to be an obstacle in accessing information. This investigation only examined the studies reported in John et al. (1987). It is our understanding that the databases examined are in constant review and development, which influenced the currency of our information.

The criteria used and displayed in Table 1 were drawn from the following published works: American Psychiatric Association Task Force, 1991; Duffy et al., 1994; John et al., 1987; Kaiser, 2000, 2001; Kaiser & Sterman, 1994; Pollock & Schneider, 1990; Thatcher, 1998. These works showed agreement in terms of the issues raised regarding standards of QEEG methodology.

Table 1 provides a summary of the participants and normality criteria. Details of sampling or recruitment were not clearly addressed by the database developers. This made it difficult to evaluate how well sound

TABLE 1. Sampling Subject Characteristics of Participants and Normality Criteria

	Hudspeth	John study 2	John study 1	Sterman-Kaiser	Thatcher
Participants Size (N)	31	120	386	135	625
Age range	NS	17-90	6-90	18-55	2 mths-83
(Children)	0	0	306	0	470
(Adults)	31	120	80	135	155
Gender	NS	63 M 57 F	NS	80% M 20% F	56.8% M 43.2% F
Normality Criteria	Interview questionnaire LNNB	Type not specified	NS adults elsewhere children	Questionnaire (appended in software manual) Oldfield Handedness	Interview questionnaire WAIS WISC and further tests

NS = Not Specified

experimental protocols had been followed throughout this stage of data collection.

The exclusion and inclusion criteria used to screen for normality were also examined. It is generally accepted among researchers that the appropriate application of well developed and relevant screening procedures promotes homogeneity of the sample being investigated (Pollock & Schneider, 1990). It is evident that there is significant variation in the size of the samples used, the age ranges reported, the percentage split between males and females and the normality criteria used. A summary of the inclusion/exclusion criteria used in each database is included below.

Hudspeth

- An interview and questionnaire
- An uneventful prenatal, perinatal and postnatal period
- No disorders of consciousness
- No reported head injuries
- No history of central nervous system diseases, convulsions or seizures due to any cause
- No abnormal deviation with regard to mental and physical development
- No reported substance or drug abuse
- Neuropsychological Testing:
    - Luria-Nebraska Neuropsychological battery
    - Met standard criteria for normality including Pathognomicity T >70
    - No more than three clinical scales with T > 70

John

Study 1: John reports that the criteria for normality and details of processing were to be found in other literature. Investigation of this revealed that this reference was for children only and the information pertaining to adults was not found.

Study 2: Self-supporting evidence

Functioning in job/household related activities

No history of head injury with loss of consciousness

No history of EEG abnormality or neurological disorders

No current prescription medications (except anti-hypertensive)

No history of drug/alcohol abuse

No subjective complaints of cognitive dysfunction

IQ estimates were in the normal range

Sterman-Kaiser

Students and lab personal (50%)

Recruited volunteers from the community (25%)

Air Force personnel including pilots, ground crew and administrative personnel (25%)

All subjects completed a handedness inventory

A questionnaire was used to screen for medical history and drug use

Recent life events (appended in accompanying manual)

The Air Force personnel used (25%) were intensively pre-screened as a condition of their service and were subject to regular medical exams and unusually high levels of drug use scrutiny.

Thatcher

Thatcher does not specify who received the testing or the different tests administered to adults or children but does report:

An uneventful prenatal, perinatal and postnatal period

No disorders of consciousness

No history of central nervous diseases

No convulsions either febrile or psychogenic

No abnormal deviation with regard to mental and physical development

Neuropsychological Testing:

Weschler Adult Intelligence Scale (WAIS) 17-adult

Weschler Intelligence Scale Children (WISC) 6-16.99 years

Other Tests

Agpar score

Vineland Social Maturity

2-3.99 yrs. McCarthy Intelligence Scale

4-5.99 yrs. Weschler pre-school & primary scale intelligence

WRAT

Grade cards from the school system

Peg board of skilled motor movements

MIT

Eight item laterality test

Hollingshead four factors of social status

Presence of environmental toxins (children only)

Table 2 contains a summary of the acquisition procedures used in database development. The development and implementation of standardized procedures in acquiring QEEG data ensures that subjects are treated in a similar fashion during all stages of data acquisition. Some authors have detailed these issues and identified the need to hold features in the environment constant. Recommendations have been made to record in the same room, use the same technician, use the same acquisition instruments, and standardize recording techniques and procedures (John et al., 1987; Kaiser, 2000). John et al. (1987, p. 453) emphatically states that " . . . in order to construct useful normative databanks . . . procedures must be meticulously standardized and precisely described." However, it appears that several of the more expansive databases were combined from disparate facilities where standardization of populations and collection methods were difficult to confirm.

Electrophysiological Procedure

All databases report similar approaches to procedures such as linked ears reference and the use of the 10/20 montage. However, there is evi-

TABLE 2. Summary of Acquisition Procedures Relating to Hardware and Software

Acquisition Hardware	Hudspeth	John study 1 & 2	Sterman-Kaiser	Thatcher
Reference	Linked ears	Linked ears	Linked ears	Linked ears
Montage	10/20	10/20	10/20	10/20
Impedance	3 K ohms	NS	5 K ohms	5 K ohms 10 K ohms
Electrodes	19 2 EOG	19	19	16 1 bipolar EOG
Acquisition Software				
Condition	Eyes closed Eyes open	Eyes closed Eyes open	Eyes closed Eyes open Task Task	Eyes closed Eyes open
Record duration	60 secs Artifact free	30-60 secs Artifact free	2-4 mins	60 secs Artifact free
Band widths	Single Hz Delta 0.5-3.5 Theta 3.5-7 Alpha 7-13 Beta 13-22	Delta 1.5-3.5 Theta 3.5-7.5 Alpha 7.5-12.5 Beta 12.5-25	Single Hz User defined Delta 1-3 Theta 3-7 Alpha 7-12 Beta 12-15 Beta 15-20	Delta 0-2 Theta 3.5-7 Alpha 7-13 Beta 13-22
Artifact method	On-line Visual	Automatic Visual	Automatic Visual State transition	Automatic Visual

NS = Not Specified

dence that other procedures were not as well standardized across databases. In particular, while nineteen channels were used for recording by three of the four databases, in the Thatcher database the montage appears to be comprised of only 16 channels, omitting the mid-line sites (Thatcher et al., 2000). It is also evident from Table 2 that the Thatcher database differs from the other databases in terms of the consistency in the level of impedance that was accepted. Thatcher reports that most of the impedance measures were less than 5 K ohms, but he does not provide specific details pertaining to the number of impedance measurements recorded which were below 5 K ohms and the number of impedance measures that were recorded between 5 K ohms and 10 K ohms.

Other areas of variation across databases were also evident. For example, only two of the four databases reported using ElectroOculogram (EOG) leads. Sterman-Kaiser also disclosed additional information not apparent from the other databases. In the Sterman-Kaiser database the EEG data recorded were subjected to 2 Hz high pass and 30 Hz low pass filters, with roll-offs of 12 and 48 dB/octave, respectively. It is specified that data were digitized at 128 samples per second. John reports time epochs of 256 sample values at a digitization rate of 100 Hz. This was also reported in the Hudspeth and Thatcher databases. Technical texts report that these factors play a role in the acquisition and evaluation of EEG data and it is important that these details are more completely reported in the future.

In terms of recording procedures, there was further evidence of variation across databases. Three databases recorded eyes-open and eyes-closed conditions only; whereas Sterman-Kaiser adds two cognitive task conditions to the data acquisition. They also limit recording length to three to four minutes, with two to four replications of each state. John reports including 60 seconds of artifact free data (or a minimum of 30 seconds of artifact free data) with a single replication in the eyes-closed condition only. Pollock and Schneider (1990) report three to five minutes of EEG acquisition under the eyes-closed, resting condition might be optimal due to the high level of variation in a subject's level of consciousness during more prolonged recordings. It is evident that there are differences of opinion about what is optimal in the length of the record and the reported length of record used in data analysis. However a key factor is homogeneity of state during recording.

Table 2 also shows that the bandwidths used varied across databases. While John and Thatcher used standard bandwidths, both Sterman-Kaiser and Hudspeth provide users with the ability to analyze single hertz bins and both of these databases offer unique data reduction capabilities not present on other systems. Some researchers now suggest that standard bands are an outdated concept. Researchers have never agreed upon standard band cutoffs and even a cursory review of the literature shows that the bandwidths used are highly variable (Duffy et al., 1984; Kaiser, 2001; Pollock & Schneider, 1990). Despite differences of opinion regarding this issue, it is logical that such variations in bandwidths affect the sensitivity of EEG measures and their comparability. This provides additional justification for the adoption of either single hertz bins or standardized bandwidths in the future development of databases.

Artifact rejection techniques were found to be similar across databases. For three databases artifact rejection occurs online and epochs are excluded if the voltage exceeds a pre-set limit. Sterman-Kaiser use wavelet analysis for estimating the period of data corruption from artifact in off-line correction. Sterman-Kaiser also provides the rationale and supporting evidence for excluding the initial 30 seconds of data due to state transition effects.

A variety of methods used to control for confounding variables were disclosed by the databases. Two issues have been targeted which we believe are worth specific consideration at this time in the genesis of normative EEG: time of day and state conditions. Table 3 provides an overview of the way the databases addressed these issues and it appears evident that these issues were only addressed in the Sterman-Kaiser database. The Thatcher database reported using randomization to control for time-of-day effects, but the methods used to achieve randomization were not disclosed and it could be inferred that any randomization was done ex-post facto in an attempt to offset less than optimal control procedures.

The SKIL database reports that it was able to obtain sufficient data to allow for the analysis of time-of-day effects. Each subject provided two to four replications of each recording condition across several time periods. These data generated a combination of cross-sectional and longitudinal outcomes over varying time categories to evaluate diurnal influences on EEG characteristics. Data provided twenty-one time-of-day categories using 274 eyes-closed and 274 eyes-open conditions. Each category was spaced in one-hour intervals every half hour. The number of subjects in each interval ranged from 15 to 19 in the 9:00 a.m. to noon intervals and 29 to 38 in the noon to 5:00 p.m. intervals. Subjects were not sampled more than once in each time interval. It was found that the active task conditions did not require time-of-day corrections. It is apparent that this variable has been contentious in its reported

TABLE 3. Summary of Two Criteria and Treatment of Confounding Variables

Controlled Variables	Hudspeth	John study 1 & 2	Sterman	Thatcher
Time-of-day	NS	NS	Specified	Random
State transitions	NS	NS	Initial 30 sec. deleted	NS

NS = Not Specified

effects on the EEG. However, Sterman and Kaiser (Sterman-Kaiser Imaging Laboratory, 2000) have provided the rationale for its inclusion together with supporting evidence from the chronobiology literature. According to Kaiser and Sterman (1994) this evidence exists and it may be optimal to include diurnal effects in a well-designed database.

The efficacy in examining task conditions in EEG spectral parameters has also been demonstrated particularly between rest and several cognitive tasks (Fernandez et al., 1994). Increasing interest in the EEG of disorders of attention indicate the need for inclusion of recording cognitive task conditions (Sterman, Kaiser, & Veigel, 1996; Sterman, 1999, 2000). This is another issue that needs to be addressed and it seems that future research and the development of specific task conditions for inclusion in each of the databases is justified.

Table 4 presents some other issues that we considered relevant in reviewing the literature. The result of extensive searches indicated that the procedures and methodology were more difficult to access for some databases than others. Specifically it was difficult to access the sample size, and a description of the normative sample used in the John database. In contrast, other database providers have this information readily available. We found that Sterman-Kaiser and Thatcher made access easy via online searches.

It would be useful for database owners to screen potential users of their databases. A potential source of unexamined variability is the lack of quality control of the clinicians who can gain access to databases. Further, there is no evidence that minimum standards of technical expertise are imposed on practitioners prior to gaining access to the data-

TABLE 4. Identified Issues of Further Concern Relating to Information Accessibility, Screening of Users and Clarity of Communication

	Hudspeth	John study 1 & 2	Sterman-Kaiser	Thatcher
Accessibility and reporting of database description	Easy	Difficult	Easy	Easy
Screening of potential users of databases such as clinicians and researchers	NS	NS	Training for new users	NS
Expression of ideas and demonstrably clear communication to the reader	Average	Challenging	Average	Average

NS = Not Specified

base services. To date, there are no set standards such as a minimum number of courses or hours of training that database owners require practitioners to complete. It is our contention that minimum levels of experience need to be acquired and ongoing training needs to be provided for people using the databases. It is also our understanding that Sterman-Kaiser require attendance at introductory and advanced training courses prior to the purchase of the software for new users.

The statistical methods used to handle the large data sets generated by EEG acquisition are complex and retain hidden assumptions. There is significant disagreement among expert statisticians over the interpretation and suitability of statistical techniques used in QEEG. We are exposed daily to conclusions based on sophisticated inferential statistical reasoning which for many is tedious and difficult.

Concerns with statistical issues have been expressed by Oken and Chiappa (1986). They suggest that statisticians review papers to prevent statistically unsophisticated readers from being exposed to papers that may contain erroneous, invalidated and chance results and conclusions. Furthermore the scientific community is responsible for preventing readers from being 'seduced' by certain techniques that may appear to be able to objectify diagnoses or evaluations. A. K. Ashbury, Editor of the *Annals of Neurology*, publisher of the Oken and Chiappa paper, added an editorial comment suggesting that even among experts there are fundamental disagreements and that for many of us statistics are obscure.

DISCUSSION

With recent advancements in computer technology the capacity to acquire real-time neurophysiology data has grown exponentially. Our intention in this article has been to draw attention to some of the issues that have emerged from this rapid growth. In particular, we have highlighted some of the differences that need to be identified and scrutinized within the normative EEG database field. Areas are identified where improvements can be made in the services provided by these databases. It is hoped that this article creates a greater interest in standardizing methodologies and reporting procedures. The failure to do so creates a continued risk of justifiable criticism by other professional industries (American Psychiatric Association Task Force, 1991). As Duffy et al. (1994) state, there is no agreed upon standard QEEG test battery or analytical process, and while this statement was made some years ago, it is our impression that there has not been much change.

The implications of this article also extend to the provision of easily understood information for practitioners. How the database owners address the issues raised in this paper and whether in the future the databases will be used more appropriately by practitioners and researchers is still to be determined. More specifically, it is important that the issue of the inappropriate use of databases be addressed and rectified through training.

Concurrently, there is the challenge of characterizing the limits of normal EEG biologic variability and the ability to distinguish this from pathological brain function. This is particularly applicable to controlling for variables such as time-of-day (Fisch & Pedley, 1989) or the use of arbitrary standard bandwidths vs. individualized custom bands. Additionally, proponents of the databases, including the developers themselves, should consider that financial or academic interests in promoting their own database could impact how their work is viewed. This reality further highlights the need for accurate, scientifically rigorous reporting and review. Reporting which is insufficient or which fails to highlight the complexities associated with the EEG signal and with its quantitative analysis misleads practitioners and the decisions they must make about their clients' treatment.

Critical to this analysis is the recognition that databases have in fact been developed over many years. Some of the differences noted seem to be a reflection of time-line development, and illustrate the importance of matching and updating database development to reflect current QEEG research.

Finally, the implications of this research identify a need to further refine existing methods and principles in order to truly develop the potentially broad ranging clinical utility of the QEEG. One requirement is to demonstrate the validity and reliability of all QEEG databases through peer-reviewed published studies. Further, it should be recognized that data cannot be combined or compared if different methods and standards are used. Even use of the same database across various studies with differences in methodology risks invalidation of the findings. The practitioner should not overlook these considerations. Nevertheless, the QEEG database has proven to be an efficacious tool that has expanded our understanding of the brain, of behavior, and of the objectives of neurotherapy.

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