Adrift in a sea of data: Assessing the effects of timing variability and drift on EEG analyses

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Introduction

Recent advances in technology have provided a variety of hardware approaches for EEG collection, including even wireless applications. Because most neuroscientific research involves the relationship between some event and a neural response, maintaining proper temporal alignment in the measurement of these factors is crucial. Most devices use a separate internal clock for data logging, and traditional techniques involve multiple stimulus/recording devices connected via trigger cable for on-line synchronization. However, post-hoc analyses commonly require additional event information, typically gathered from 3rd party log files which often are not synchronized.

Unfortunately, relying on a secondary data source can also introduce errors related to ADC clock jitter and drift, with potential dramatic effects if not properly considered.

Here, we discuss the timing and related characteristics of several contemporary EEG systems, including advanced wireless devices intended for mobile recording (Advanced Brain Monitoring, Emotiv, & Quasar) and standard "fixed laboratory" wired (Biosemi) applications.

We also illustrate the practical ramifications of the amount of error seen in these systems on averaged ERPs, using both simulated and real human data.

Methods

Calibration

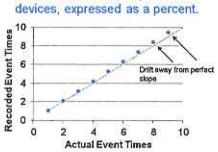
Must confirm that E-Prime based data log is reliable

2-step process for confirming timing consistency of the recording equipment

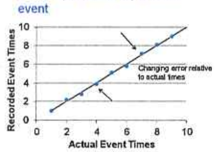
- Compared calibrated function generator @ 10 Hz, recorded via Parallel Port; Data log variance < 0.01 ms
- Compared triggers sent OUT via Parallel Port from STIM PC to recorded times (ACQ PC); also <0.01 ms variance

Measurements

Temporal Drift – Relative difference in time as measured by two devices, expressed as a percent.



Timing Jitter – Mean variability in the times reported for a particular event



Event triggers (500, 1250ms ISI) were input into each EEG system via external cabling using E-Prime 2.0 on a 2nd Windows XP PC using either the parallel (Biosemi, ABM, Quasar) or serial (Emotiv) port. Data were collected using the native sample rate of the system and COTS collection software provided by the vendor.

Data from the ABM X10 system are presented from two different firmware versions, stated as **A & B**. Emotiv data were collected using both the current full release of Test Bench, and the most current Beta version.

Datasets

Simulations – Drift and jitter were simulated by multiplying the observed values (shown in Table 1) by a series of 200 trials consisting of **(A)** 10 Hz square waves with 4 sec ISI, and **(B)** an example human subject's ERP data from an 8-min VEP paradigm.

Human VEP – 7 human subjects performed an oddball discrimination VEP-eliciting task. Eyeblink artifacts were removed using ICA with grand means calculated in ERPLab and presented using the original event timing, events imported from a separate log file but not corrected for drift, and the same log file using a correction algorithm.

Results

Drift/Variance Observed

A wide range of timing drift and variance is observed across different EEG systems.

System Mfr	Drift (%)	Mean Error (ms)	Std. Dev. Error (+/- ms)	Sample Rate	Acq. S/W
ABM: A	0.027575	0.344689	0.479946	256	B-Alert 2.45
ABM: B	0.002565	0.032064	0.281587	256	B-Alert 2.45
Biosemi	0.001879	0.023484	0.109064	512	ActiView 6.05
Emotiv	0.106463	1.330787	55.705045	128	TestBench 1.5.0.3
Emotiv	0.107132	5.250727	69.147220	128	TestBench 1.5.1.2
Quasar	-0.000626	-0.007828	0.123526	240	Qstreamer 1.5.1046

Table 1. Timing drift can range from negligible (e.g. Quasar) to extreme (Emotiv) relative to a standard clock; note the 10x difference in ABM firmware versions. While most systems show very small variance, the Emotiv Epoc is highly inconsistent.

Simulations - Temporal Drift

Simulations of the observed drift illustrate dramatic implications for the accuracy of an averaged waveform

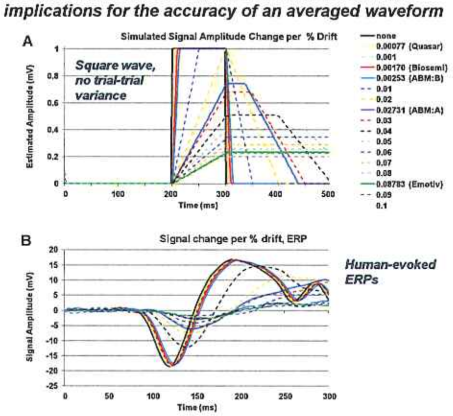


Figure 1. The simulated effect of a range of hypothetical timing drift values (dashed lines), as well as those observed in these systems (solid lines), applied to a simple square wave function (A) and single-subject ERP data (B) consisting of 125 trials over 8.33 min.

The overall effect is that of widening the base of the function, while distorting the slope and suppressing the overall peak; the effect observed with the drift measured in the original ABM firmware (ABM: A, 0.0278) is a 12% decrease in amplitude and near doubling of base width, while the peak with Emotiv-simulated drift is suppressed by > 76% .

The impact of drift increases with recording length; however this interaction is dramatic only with severe drift.

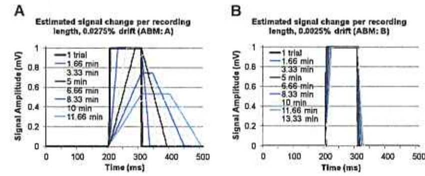


Figure 2. The error is progressive, thus the extent of the effect increases as the length of recording increases. Here we show the effect of different total record lengths (typical for EEG) for two observed drift amounts – from the two different ABM firmware versions. Note here with the larger amount of drift **(A)**, a notable effect on the signal waveform occurs within only a few minutes of recording time. Meanwhile, if the drift is much smaller, the overall effect is relatively minimal (B).

Simulations - Jitter

Excessive stimulus-record jitter can also dramatically affect average waveform accuracy.

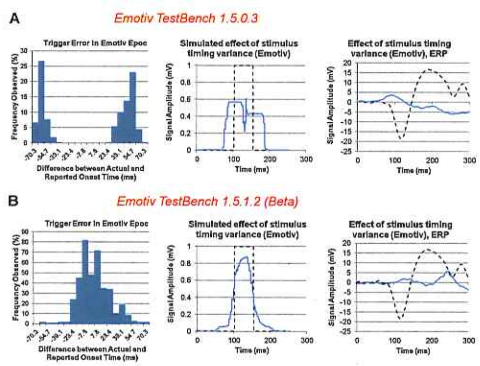


Figure 3. Simulating the excessive variability within the Emotiv TestBench trigger integration software (2 software versions shown) causes extreme degradation of an averaged signal, especially ERPs (far right). The minimal variance of other systems (<1 ms) had no measurable effect.

Multi-Subject ERP Data - Drift & Correction

Accounting for known drift and variance can not only correct the errors but also provide overall better signal quality.

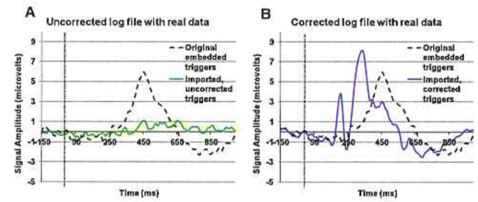


Figure 5. Data represent grand mean averages of a visual-evoked response from 7 subjects. While using imported data that does not account for drift can lead to a degraded signal (A), using a secondary log file from a jitter-free source which corrects for this error can actually lead to an improved signal (B) due to higher-precision timing on the logging device.

Conclusions

- *A wide range of clock drift and stimulus trigger jitter was observed across several different contemporary EEG systems; wireless systems were not necessarily any worse than the conventional wired method.*
- *If unaccounted for when referring to 3rd party data files, drift can dramatically influence the shape of averaged waveforms.*
- *When moderate drift occurs, recording sessions of length typical for behavioral studies can be heavily impacted.*
- *Excessive jitter could functionally destroy a target ERP signal*
- *Using an algorithm to account for drift in a 3rd party log file can correct the problem, and even improve signal clarity in high-jitter systems.*

In summary, we have shown here that a wide range of timing drift and variance occurs across different EEG systems relative to a standard system clock. Depending on the extent of drift that occurs, it could be potentially catastrophic for averaged evoked potential analyses, and thus must be monitored carefully. In cases where secondary data files must be referenced, lab personnel should consider using an additional synchronization algorithm which we have shown to properly compensate for drift-related errors.

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