Filter comparison - BrainMaster and EEG Spectrum systems

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Introduction

This report compares the filter characteristics of two EEG neurofeedback systems. These are the EEG Spectrum system (also known as "Neurocybernetics"), and the BrainMaster 2E (Version 1.8 beta). Both the old and new designs of the EEG Spectrum system were tested, and results were seen to be the same, so this study should apply to all EEG Spectrum systems.

Differences in the filtering systems are measured, described, and discussed. There is some speculation about the meaning and importance of the differences, and things that can be done.

Executive Summary

The systems were compared with a signal generator, and critical measurements were taken.

The EEG Spectrum filters were observed to respond more quickly to transients than the BrainMaster filters. In the experimental design, they were as much as 130 milliseconds faster at responding to quickly changing signals. In clinical use, this probably translates to a 30 to 65 millisecond speed difference. This performance is achieved at the expense of poorer selectivity of the filters, especially to transient changes. The EEG Spectrum filters had between 2 and 10 times more error in responding to transient changes. Errors were between 32% and 72% in all filters measured. The BrainMaster filters, in contrast, had errors of this type between 5% and 25%. In the case of steady-state error, the EEG Spectrum filters had between 4% and 20% false signal, while the BrainMaster filters had between 0% and 5%.

The origin and significance of these differences are discussed at the end of this report.

Methods

Both systems were tested by using a signal generator that produced 20 microvolts peak-to-peak, and could be turned on and off. The systems were tested for transient response by turning on the signal generator, and observing the resulting signals on the raw and filtered EEG waveform outputs. After the filter outputs reached their steady state, the steady-state responses were also measured.

Explanation of measurements

For each set of measurements, the signal generator is centered in frequency at the center of a "target" filter. This is the filter being tested. For this filter, the response time is measured and reported. All other filters are also observed, to measure the leak-through, which is the output of a filter that is not set at the target frequency. Leak-through indicates that the system will respond to a particular frequency in other filters than are intended to respond, thus producing false feedback, and is a source

of error in the system.

Because these measurements were made by turning the signal generator on and off, the measurements represent a worst-case, and do not reflect the actual circumstances encountered in biofeedback. In real EEG, signals do not turn on and off sharply, but wax and wane. For this reason, the measurements and analysis presented here are only for comparison purposes, and do not represent actual clinically meaningful figures. Also, the timing was taken to full filter output, which is also not required in practical biofeedback. The user will receive feedback information well before the filters have reached full response. The response times reported here are, therefore, much longer than encountered in actual use, and should not be quoted as actual clinical values.

Because of limitations in the ability to measure all the filters in the EEG Spectrum system, and to simplify the study, all possible combinations of filters were not tested. This is reflected in the choice of columns and rows in the reported data. With the EEG Spectrum system, only 3 filters can be tested at a given time. The BrainMaster is capable of computing and displaying all 8 filters. However, in order to compare with the EEG Spectrum system, only the bands measured in the EEG Spectrum system were measured with the BrainMaster.

Filter Response time

This was measured by observing the time necessary for the system to visually reach its full output. This number is useful for comparison purposes only, and does not represent the actual response time in biofeedback applications. The trainee will observe a change well before the signal reaches its full output. However, this provides a useful figure for comparison purposes. The full-signal response time is actually 3 to 5 times the response "time constant" of the filter.

In addition to the time required for the signal to reach its full output, the time for the user to see a full response was estimated. In the case of the EEG Spectrum system, this was taken to be the full output time, plus 1 cycle of the input wave. This is to allow for the time necessary for the envelope detection method to find the maximum peak-to-peak transition in the waveform. In the case of the BrainMaster, this is identical to the full output time, because the quadrature filter design automatically extracts the envelope as part of the filtering operation, and no separate envelope detection step is required. Again, this number is for comparison purposes, only.

Transient Leak-through

This is measured by observing the largest transient output of each filter, as the signal is turned on or off. It is defined as a percentage of the steady-state full-scale output of the target filter.

Steady-state Leak-through

This is measured by observing the steady-state output of each filter while the input signal is presented. It is defined as a percentage of the steady-state full-scale output of the target filter.

Delay times (note that these experimentally measured values are for comparison purposes only. Actual delays in biofeedback situations would be 25% to 50% of these values):

Parameter	EEG Spectrum	BrainMaster
Theta (4-7) delay to full feedback	400 ms	500 ms
Low Beta (12-15) (SMR) delay to full feedback	300 ms	430 ms
Beta (15-18) delay to full feedback	355 ms	410 ms

Transient Leak-Through (percent of steady-state response)

Parameter	EEG Spectrum	BrainMaster
Beta filter response to theta wave	72%	15%
Hi Beta filter response to theta wave	40%	<5%
Theta filter response to Low Beta wave	40%	25%
Hi Beta filter response to Low Beta wave	36%	<5%
Theta filter response to Beta wave	40%	20%
Hi Beta filter response to Beta wave	32%	<5%

Steady-state Leak-through (percent of steady-state response)

Parameter	EEG Spectrum	BrainMaster
Beta filter response to theta wave	20%	0%
Hi Beta filter response to theta wave	12%	0%
Theta filter response to Low Beta wave	4%	<5%
Hi Beta filter response to Low Beta wave	16%	0%
Theta filter response to Beta wave	8%	0%
Hi Beta filter response to Beta wave	20%	0%

Technical Discussion

The measured differences are largely due to the choice of filter type and "order" in the systems. The EEG Spectrum system has filters that have been chosen primarily for good transient response. The BrainMaster system has filters that have been chosen primarily for good rejection of "out-of-band" signals.

The BrainMaster uses filters that are 6^{th} order Butterworth, quadrature type. These are documented in publications provided by BrainMaster Technologies. This filter type has a very steep cutoff at the edges of the passbands, producing superior rejection of out-of-band signals.

It is a fact that the slope of the passband edges has a direct impact on transient response. This is because a transient waveform produces sidebands that must be passed by the filter, if it is to respond to the changes.

The importance of this in biofeedback is open to interpretation. The feedback signal must be rapid, but it must also be accurate. There is no "magic bullet" that will make a set of filters that are perfect for every situation.

Anecdotal reports and clinical results show that both systems have good efficacy in real-world applications.

Speculative Discussion

The choice of slope of the band edge is largely a matter of opinion and taste. Whether or not fast response is more important than accurate response has not been studied experimentally. This study suggests that it should be.

As a matter of speculation, we can think of the sharpness of the passband, and the spectral purity of the filters, as a parameter that distinguishes the biofeedback system. The trainee on a BrainMaster system may notice slower response, but they may also notice a truer response. Thus, the trainee may need to do a better job of producing (or inhibiting) the sustained rhythm, but they are also less likely to receive confusing information during the training.

Another analogy may be to the weight used for physical training. It is as if the EEG Spectrum system is using "lighter" weights, thus making it easier for the individual to move the weight to a desired location. The BrainMaster weights may be a bit heavier, requiring more work. However, they may produce a stronger effect, as training progresses.

Finally, it is noted that it is possible to design the filter system in any way that the designer deems appropriate. It is likely that the slope of the passband should be selectable by the user. This is a design feature that will be considered in upcoming versions of the BrainMaster system.