A VESTIBULAR DIAGNOSTIC: BALANCE PLATFORM

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Abstract: The control of balance is achieved mainly through the integration of information coming from the vestibular organs in each ear. The extent of its control is recognized when dysfunctions of the vestibular system occur. This is seen in the abrupt dizziness of Meniere’s disease, which is related to the imbalance of input between the two vestibular systems [1]. To determine the deterioration of vestibular function or to demonstrate the efficacy of therapeutic or drug interventions on the vestibular system, a prototype method of the ongoing assessment of balance disorder was developed. The system uses a wavelet decomposition of a balance plate recording to find the frequency content of healthy and balance impaired subjects during a variety of balancing tasks. Two main frequency bands (3-9Hz and 11-16Hz) were observed as likely components reflecting vestibular health.

Key Words: Vestibular Diagnosis, Meniere’s Disease, Balance.

Introduction:

Electrocochleography (ECOG) is a variant of the brainstem audio evoked response where the recording electrode is placed as close as practical to the cochlea. It is intended to diagnose Meniere’s disease and, in particular, hydrops [2]. For the SP/AP ratio AP stands for the action potential. The conventional explanation for the summating potential (SP) of ECOG is that there is a nonlinear response in Ressner’s membrane caused by elevated endolymphatic pressure and distension [2]. The ECOG is neither 100% sensitive nor 100% specific [2]. You can have Meniere’s disease and a normal ECOG, and you can also have an abnormal ECOG but not have Meniere’s disease [2]. Other tests or improved methods are required. Other balance measures have been explored [e.g. 3, 4,5,6]. One group of measures involves the use of a balance platform. This paper describes the use of a balance platform wherein the recorded signal is analysed, following removal of background signals and artifacts, with a time frequency wavelet decomposition technique. The method, if successful, has the potential for improved detectability of vestibular dysfunction in the otolithic organ components (the saccule, utricle, semi circular canals) but also the disadvantage of less specificity in terms of vestibular disfunction origin.

Objective: To examine the selectivity of balance plate recordings for the detection of vestibular dysfunction and subsequent efficacy of interventions.

Background: It is known that skeletal muscle activity recorded from the skin using electromyograms (EMG), has a broad frequency distribution from 0- 200 Hz with several more or less distinct spectral components [7]. These include a 0–5 Hz component thought to reflect common drive to the motor units, a 10 Hz component thought to reflect motor unit firing and physiological tremor, 20–30 Hz component (the so-called EMG beta rhythm), and a 35–60 Hz component (the Piper rhythm). EMG from facial muscles also shows a broad frequency distribution from 0 Hz up, with two peaks corresponding to the EMG beta and Piper rhythms. Essential tremor occurs around 5Hz [8]. Primary orthostatic tremor consists of rhythmical muscle contractions at frequencies around 12-18Hz that can cause unsteadiness while standing [8]. Accordingly frequency bands examined herein will be from 0-50Hz.

To extract further information from a recorded time domain signal it can be transformed into another domain. Fourier analysis will break a signal down into its various frequency components using sine and cosine as the basic building blocks. The drawback of these building blocks is that they are only appropriate for modeling time independent wavelike features [9] and takes a large number of Fourier components to model a sharp corner [10]. Wavelet analysis uses wavelets as a building block for a more accurate local description and separation of temporal events. They are suitable for transient signals, such as the ones recorded in this study as well as stationary signals. A mother wavelet can be scaled to obtain higher and lower frequency wavelets. As the scale increases the wavelet becomes narrower allowing a representation of higher resolution. The Morlet wavelet was chosen for its excellent time-frequency localization properties [10].

Methods: A balance floor was used to record body sway. The balance floor consisted of a set of digital scales that had the top removed so that a custom made platform could be placed on the piezoelectric sensor. The electrical signal was amplified using CED 1902 biological amplifier with a gain of 3000 with a built in notch filter set at 50 Hz. Signals from the balance floor were recorded using
Adobe Audition 1.0 at a sample rate of 44100 samples/sec into a mono channel with a 16-bit resolution. Recordings were done in a shielded room. No low or high pass filtering was applied to the recording.

For the removal of background signal it was originally intended that a recording of the subject standing relaxed could be used. However this recording would contain natural sway that would be subtracted from later recordings, leading to loss of information. Instead, a variety of weights adding up to 70kg were placed on the platform and the signal recorded. Ten seconds of the 70kg weight recording was used to remove noise from the recorded signal from a subject. It was originally thought that this trace could be applied universally to all subjects but as the study progressed it was evident that the noise varied from day to day. So a recording of the 70kg weight was taken at the beginning of each recording for each subject and then used for noise removal for that subject.

The position of the subject on the platform could also possibly influence the recording. Recordings were taken with all subjects facing the same direction on the balance platform standing on top of a set of drawn footprints.

The tests included the subject standing facing the front, hands by their side with their eyes open then closed. Next subjects were asked to stand on their right foot then their left foot hands crossed over their chest with eyes open then closed. All recordings were forty seconds in duration and subjects took a break for at least one minute in between trials to rest their legs. Once the recording was finished Adobe Audition 1.0 automatically performed a fast Fourier transform of the data so any presence of harmonics could be detected and problems rectified. To observe if an improvement (motor learning/familiarity) had taken place the subject was asked to come in around the same time the following day to repeat the tests.

Ten seconds of a recording and ten seconds of noise were extracted then combined serially and saved as a WAV file. This file was then analysed using wavelet decomposition with a Morlet wavelet [2] to find the frequency content of the signal with or without background. The frequency content of the signal was graphed. All figures herein have background spectra removed.

A ‘normal’ population (n=8) was compared to two subjects that have suffered or still suffer from a chronic balance disturbance. Subject 8 started suffering from Meniere’s disease roughly 10 years ago and activities such as bending down and looking under a table will induce vertigo. Subject 9 suffers from transient onset vertigo at least every two weeks and this can occur every day. As a result they found it very difficult to balance on one leg with eyes closed. Figures displaying normal population results are the average of the eight subjects for a particular condition.

Results:
General observations:
1. Generally subjects performed better on the second day (figure 2).
2. There was greater learning (smaller wavelet coefficient magnitudes) for the non dominant leg for the eyes closed condition (figure 1).
3. There was better balance (smaller wavelet coefficient magnitudes) on the dominant leg with the eyes closed (figures 2, 3).
4. For eyes closed there appeared to be a slight increase in frequency wavelet coefficient magnitude for the dominant leg in the 13-15 Hz band on day 2. The reverse was true for the non dominant leg (figure 2).
5. Eyes open performance was better (smaller wavelet coefficient magnitudes) than eyes closed (figures 2, 3).
6. When balancing on one leg with the eyes open the subjects showed a similar although lower wavelet coefficient magnitude pattern on the second day for that particular leg (figure 3).
7. From the normal population there is a trend for the wavelet coefficient magnitude to decrease on the second day. The exception is for eyes closed on the dominant leg where on day two the 15 Hz component increases (figures 2,3).
8. After observing the individual traces of the ‘normal’ population it was found that common major frequency peaks occurred at 4, 7, 11 and 15Hz.
9. Balance impaired subjects require significantly larger effort (magnitude of wavelet coefficients) to stand on both legs. This effort is focused at 7 and 10Hz (figure 4). Note: there is a scale difference between plots for the disorder and the normal group.

A comparison of subjects 8 and 9 (vestibular disorders) to the averaged control group are presented in the following figures.

General observations:
10. When balancing on the dominant leg with eyes closed the balance impaired subject had no “high” frequency peaks around 15 Hz but rather peaks shifted to 7 and or 10 Hz (figure 5).
11. When balancing on the non dominant leg with eyes closed the balance impaired subject 8 had an increased low frequency content and magnitude of averaged wavelet coefficients. Frequency peaks at 6, 8 and 15Hz were also present (figure 5).
12. When balancing on the dominant leg with eyes open the balance impaired subjects had no “high” frequency peak around 15Hz but rather two peaks around 5 and 10 Hz. The magnitudes of these peaks were more than 20 times larger than for normal subjects (figure 6).
13. When balancing on the non dominant leg with eyes open the balance impaired subject 8 had an elevated though relatively normal response compared to subject 9 whose frequency peak locations were shifted to 4 and 7Hz and significantly elevated (figure 6).
14. “Effort” (magnitude of the wavelet coefficients) on the dominant leg is greater than that of the non dominant leg. This difference is exacerbated in the balance impaired (figures 2,3,5,6).

Discussion and Conclusion: The system as described has shown that patients with balance disorders dedicate significantly more effort to maintaining balance (figure 3). Furthermore, balance tests on balance impaired
subjects incorporating single leg balance tests might be useful in providing evidence for locating the faulty mechanism. For example the eyes open/close comparison might point to problems in the vestibular-ocular pathway.

A most interesting observation was the significantly larger wavelet coefficient magnitudes, for the dominant versus non dominant leg recordings, in balance impaired subjects. This suggests that future observations might fruitfully look at the magnitude ratios obtained from dominant/non dominant leg recordings.

A second interesting observation was that this analysis method showed in the normal population a frequency peak at about 15Hz which has been used to characterize orthostatic tremor [8]. [8] did not appear to find this frequency peak to be significant in their normal population.

These preliminary tests show the promise of wavelet based, background removing, balance platform systems in assisting in and perhaps better extracting balance information for balance disorder screening.

Figure 5 Comparison of subject 8 (diamonds) and the control group (squares) balancing on their dominant leg (upper plot) and non dominant (lower plot) leg. Both plots are for day 1 with eyes closed. (note: subject 9 could not balance on one leg with their eyes closed). Scales as per previous plots.

Figure 6 Comparison of subjects 8 (diamond) and 9 (square) balancing on their dominant (upper plot) and non dominant (lower plot) leg with eyes open on day 1. Triangle are averaged normals. Scales as per previous plots.

REFERENCES


