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SeeSway – A free web-based system for analysing and exploring standing balance data

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ABSTRACT

Background and objectives: Computerised posturography can be used to assess standing balance, and can predict poor functional outcomes in many clinical populations. A key limitation is the disparate signal filtering and analysis techniques, with many methods requiring custom computer programs. This paper discusses the creation of a freely available web-based software program, SeeSway (www.rehabtools.org/seesway), which was designed to provide powerful tools for pre-processing, analysing and visualising standing balance data in an easy to use and platform independent website.

Methods: SeeSway links an interactive web platform with file upload capability to software systems including LabVIEW, Matlab, Python and R to perform the data filtering, analysis and visualisation of standing balance data. Input data can consist of any signal that comprises an anterior-posterior and medial-lateral coordinate trace such as center of pressure or mass displacement. This allows it to be used with systems including criterion reference commercial force platforms and three dimensional motion analysis, smartphones, accelerometers and low-cost technology such as Nintendo Wii Balance Board and Microsoft Kinect. Filtering options include Butterworth, weighted and unweighted moving average, and discrete wavelet transforms. Analysis methods include standard techniques such as path length, amplitude, and root mean square in addition to less common but potentially promising methods such as sample entropy, detrended fluctuation analysis and multiresolution wavelet analysis. These data are visualised using scalograms, which chart the change in frequency content over time, scatterplots and standard line charts. This provides the user with a detailed understanding of their results, and how their different pre-processing and analysis method selections affect their findings.

Results: An example of the data analysis techniques is provided in the paper, with graphical representation of how advanced analysis methods can better discriminate between someone with neurological impairment and a healthy control.

Conclusions: The goal of SeeSway is to provide a simple yet powerful educational and research tool to explore how standing balance is affected in aging and clinical populations.

Introduction

Computerised posturography can be used to assess aspects of standing balance that are not possible from clinical tests, such as timed standing or subjective rating scales (e.g. Berg Balance Scale). A common method of assessment is to perform a static standing trial during which a person's postural sway is collected using outcome measures such as center of pressure (COP) or center of mass displacement [1]. These assessments can provide an insight into how much a person sways when they are attempting to stand naturally. Excessive sway, or the opposite presentation of excessive rigidity, may indicate an impaired neural control strategy and could be an early predictor of poor long term outcomes such as falls [2]. Balance impairments are also prevalent in many clinical populations, including hearing loss [3], idiopathic neck pain [4], post-surgery [5], cancer [6], joint injury [7], and chronic obstructive pulmonary disease [8].

Prior to the current decade the implementation of posturography was very limited, as it required expensive systems such as commercial force platforms or inertial monitoring units [9]. However, an influx of low-cost, widely accessible technology that either includes or provides an alternative to these sensors has become available. For example, studies have shown that systems including the Nintendo Wii Balance Board [10–12], Microsoft Kinect [13,14],

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and smartphones [15] provide valid data for quantifying postural sway. Importantly, the creation of these systems has allowed for their use in assessing clinical populations, with a number of studies showing their ability to discriminate between healthy and clinical populations [16–18], identify longitudinal changes in function [19–21] and predict poor outcomes [22–24].

A major limitation of computerised posturography is that the data acquisition and processing techniques used can have a very large impact on the results of some outcome measures, and this makes comparison and compilation of data across studies fraught with error [25]. While it is difficult to standardise data acquisition hardware across research centers, it may be possible to provide a standardised analysis framework for posturography related data analysis to ensure consistency across studies. An issue with this is that it is still unknown what the optimal signal preparation and analysis methods are for specific populations and assessments. There are a wide variety of filtering techniques, including traditional finite impulse response (for example the Butterworth filter) and wavelet filter banks. Furthermore, the optimal filtering thresholds can vary between assessment tasks, with single leg standing requiring a higher lowpass frequency threshold than double leg standing. Additionally, analysis methods range from the simple (for example – calculating the maximum range the COP moved during a trial) through to the complex (for example – detrended fluctuation analysis). The lack of definitive guidelines is partly due to the limited research in the area, and the difficulty in comparing filtering methods and outcome measures due to the need to create custom software to perform these analyses.

In an effort to overcome these issues, we have created an online, platform independent interactive webpage that allows the user to easily examine their data using different filtering and analysis techniques. This paper describes the creation of a freely available, internet-based software package (SeeSway, available at http://www.rehabtools.org/seesway.html) for pre-processing and analysing posturography data that is compatible with any device that exports raw postural sway related data.

Design considerations

The online analysis program interacts with the user in the same manner as a standard dynamic website. SeeSway is built using a combination of standard website programming languages including HTML, Javascript, PHP and CSS. The novelty of this system is that the website is linked to server-hosted LabVIEW, Matlab and C# executables and dynamic link libraries via a Websockets protocol, with the capacity to access other programming languages such as Python and R via a backend command line interface hosted on the local server. This allows for simplified access to the user input data, distribution and processing of the data on computers linked to the server computer (at the time of writing: Windows 8 Professional Core-i7 with 16Gb RAM and 500GB solid state hard drive), and reporting back to the user. This flexible combination of software systems has the potential to allow for interaction with code created in all major programming languages, and any server-hostable visualisation software that produces HTML output such as Highcharts and Plotly.

A variety of methods were explored to link the user interface webpage with the analysis programs. A decision was made to integrate Websockets due to its cross-platform compatibility and its ease of data transfer with the server hosted Ubuntu virtual machine. Data transfer was achieved using Labsockets (Bergman Mechatronics, USA), which is a software program designed to replicate a LabVIEW graphical user interface in a PHP format. This portal allows for LabVIEW programs to be run natively, but also allows for interfacing with other programming languages and compiled executables via methods such as .NET and ActiveX calls or using the inbuilt functions such as the Matlab Script node. Importantly, the individual programs which are represented as websites can be run on remote computers yet still hosted on the server. As an example, during debugging the SeeSway program was being tested on a computer in Singapore which sent the webpage to the server in Australia where it was hosted. This results in the ability to minimise the computing requirements of the server by simply adding more computers to run any additional programs, with the server only hosting the resulting webpages.

Description of method/system

SeeSway provides a suite of signal pre-processing, analysis and visualisation methods that can help the user optimise the quality of their data and explore analysis techniques that could provide insight into the standing balance of their participants. These include:

Pre-processing filtering protocols

1. Lowpass Butterworth filter. This includes a selectable filter cut-off threshold (defaults to 10 Hz) and order (defaults to 6th order). The Butterworth filter is implemented using a reflection padding method, which creates reversed copies of the dataset and appends these to the start and end of the original dataset, performs the filtering, then removes these padded segments before further analysis [26].
2. Non-weighted and weighted moving average filters. The non-weighted moving average filter is a simple mean filter (default 5 samples length), and while these are not commonly used for analysis they are very effective at removing transient noise from a signal at the expense of frequency domain signal integrity. The weighted moving average method is a Henderson 13-term moving average filter [27].
3. Wavelet-transform based filtering. Discrete wavelet transform filters have numerous potential benefits in terms of processing discrete, non-linear signals. Their drawbacks include a lack of precision with respect to filter cut-off thresholds due to their usage of cascading filter banks. Therefore three iterations are provided in the analysis program, with lowpass cut-offs of 12.5 Hz, 6.25 Hz and 3.125 Hz available. The Symlet-8 wavelet was chosen as the mother wavelet as it was deemed to most closely match the shape of the COP signal, however it provides almost identical results to other wavelets such as higher order Coiflet and Daubechies wavelets for posturography analysis [28]. The website defaults to the Symlet-8 wavelet filter.

The effect these filters have on the data are displayed graphically, and in the time-frequency domain using scalograms derived from a Complex Morlet continuous wavelet transform. This allows the user to examine their data to determine the optimal filtering method for their specific tasks.

Data analysis

The current iteration of the website takes three one-dimensional arrays from a single spreadsheet file, in each of the first three columns. The first array consists of the medial-lateral data, the second array the anterior-posterior data and the third array corresponds to vertical force. As per standard posturography analysis, the first two arrays are analysed independently to calculate axis specific results. These two arrays are also combined using basic Pythagoras theory to determine a combined axis displacement for each sample point, from which total scores are derived. The third axis is only used to obtain body mass and vertical force fluctuation measures. To aid in conversion of the end-users data to this format, we have provided