The Expanded Automatic Assessment of Postural Stability: the xAAPS

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INTRODUCTION

Mild Traumatic Brain Injury (mTBI) can lead to temporary or permanent impairment of cognitive, physical and physiological functions and it represents a contributing factor to a substantial number of deaths and permanent disability [1].

mTBI is best detected when the evaluation of possible exposure is carried out in the field, at the earliest opportunity. The Balance Error Scoring System (BESS), which is a brief and easily administered test of static balance, has been devised to detect balance deficits, arising from concussion and musculoskeletal injuries, in the field [2]. The BESS presents four main limitations: 1) it requires the presence of a trained (clinical) observer to score the test; 2) the test-to-test reliability can be biased by the manual scoring system; 3) A visually scored test can result in under-reporting some of the symptoms; 4) The BESS test only measures static posture. To address these limitations, we have developed the Automated Assessment of Postural Stability (AAPS) system, that is an easy to set-up, computerized and quantitative system for automatically administering and scoring the BESS test in a wide variety of non-clinic locations using inexpensive off-the-shelf devices [3], [4].

Furthermore, in order to provide a more comprehensive concussion evaluation tool we are developing the expanded AAPS (xAAPS) to introduce the evaluation of dynamic balance tasks. The xAAPS capability of evaluating coordinated dynamic movements will potentially provide more salient feedback for assessing concussion and suitability for return to duty than using static balance measures alone.

METHODS

The xAAPS system consists of two hardware components: a Windows laptop and a Microsoft Kinect 2.0 device, paired with a custom-developed Windows software application. The xAAPS software has been designed and developed to be user-friendly and to guide the operator through all the necessary steps to correctly administer the testing protocols. At the end of each trial, the xAAPS automatically evaluates, displays and stores the balance scores in under a minute. The xAAPS features a custom developed balance evaluation method based on computer classification algorithms that convert the subject's three-dimensional joint center positions (as derived from the Kinect sensor) into balance metrics. These metrics are equivalent to Functional Movement Screening (FMS) [5] scores assigned by an experienced observer. The FMS consists of seven movement patterns scored on a scale of 0-3 points, where 0 means pain and 3 a perfect execution. The current version of xAAPS focuses on continuous multi-repetition versions of the first three of the seven FMS assessments: Deep Squat (DS), Hurdle Step (HS) and In-line Lunge (ILL).

In order to validate the performance of the xAAPS scoring algorithm, we asked 26 young adults (12 male / 14 female) to perform the three FMS movements while their kinematic data were captured with the xAAPS system. To obtain reference data for comparison, video recordings of the movement tests were scored by an experienced observer. Those scores were then used as labels for the dataset when training the xAAPS classification algorithm.

More specifically, the xAAPS extracts 3D joint coordinates from the Kinect data stream. The Kinect generates these data at a variable sampling frequency, which is then resampled off-line to a constant rate of 30 fps. Subsequently, the resampled joint position time series are low-pass filtered with a fifth order Butterworth with cutoff frequency set at 2Hz to reduce measurement noise. The next step in the signal processing cascade is to extract features that can be successfully used to train a set of classification algorithms. For each trial, a total of 27 kinematic features are extracted and used to evaluate each trial quality. The extracted features range from commonly used kinematic metrics, such as range, mean and standard deviation of velocity, acceleration and jerk of the Center of Mass (COM) trajectory, to more complex features such as spectral power, coefficient of variation and continuous relative phase variability [6] of the COM. Dynamic Time Warping (DTW) distances of COM and Principal Component Analysis (PCA) of the joint 3D displacement time series [7] were also used as features. Next, we trained a set of gold-standard classification algorithms such as, Decision Trees, Support Vector Machine (SVM), k-Nearest Neighbors (k-NN) and Ensemble Bagged Trees. These classifiers' predictive performance was assessed using a 3-fold cross-validation approach. Finally, for each movement type, the optimal combination of features and classification algorithms were identified.

RESULTS

The xAAPS can successfully score the three FMS movements (HS, ILL and DS), with scoring performance well above random classification levels, that given the distribution of our sample population, are 57.1%, 42.3% and 67.7%, respectively. Specifically, the xAAPS displayed the best scoring performance for DS trials, using a SVM classifier with a cross-validated prediction accuracy of 92.3%. The HS assessment accuracy was 84.6% using a Decision Tree algorithm and finally accuracy of 69.2% was measured for ILL using an Ensemble Bagged Tree approach. Furthermore, qualitative analysis of kinematic data time series, indicates that the xAAPS lower performance for ILL trials is due to larger inaccuracies of the Kinect body tracking algorithm when detecting the lower-extremity movements for ILL motion.

CONCLUSION

Our laboratory has recently shown that Kinect 2.0™ data is suitable for instrumenting simple field-expedient clinical static postural stability tests such as the BESS [3]. With the present work, we present the xAAPS, an expanded version of the reliable and quantitative Automated Assessment of Postural Stability (AAPS). The statistical performance of the innovative xAAPS algorithms in predicting the human-assigned FMS scores for three movements, namely HS, ILL and DS, as performed by 26 subjects, shows that the xAAPS can be a valuable in-field expedient to evaluate dynamic balance, without the need of human scorers.

Furthermore, despite the current version of the system being optimized for three specific movements, the feature extraction and classification algorithms have been designed to be flexible, easily adjustable and re-trainable for the evaluation of further motion types and different clinical testing protocols.

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ACKNOWLEDGMENTS

This work was supported by DoD/USAMRMC Award # W81XWH-15-1-0445.

DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.