

Automatic Evaluation on Trunk Coordination Ability Using Portable Devices: Feasibility and Preliminary Results

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In this study we aim to utilize portable devices to evaluate trunk coordination ability. We investigated the feasibility of using accelerometer and Nintendo Wii balance board as alternatives to expensive and bulky motion capture systems for differentiating good and poor coordination ability. We extracted time and frequency domain features from data collected using the two devices, and investigated the differentiating power of these features. We found that the features of accelerometers were more powerful than those of Wii balance board. Further study is required to build a computational model for automatic classification of good and poor coordination ability.

Key words: mobile health, pervasive computing, core strength, accelerometer, Wii balance board

1. Introduction

Trunk strength is critical for healthy aging, as weak trunk is often related to lower back pain and fall accident in elderly population [1-2]. Most of existing research and training programs on trunk strength was focused on how to measure and improve trunk muscle strength [3]. However, a revisit to the definition of trunk strength suggests that both muscle strength and neuromuscular control play important roles in achieving and sustaining control of the trunk region at rest and during precise movement [4], and there is increasing evidence that neuromuscular control is even more critical in providing sufficient trunk strength and is yet not strongly associated to trunk muscle strength [5-6].

Since intensive trunk muscle training is not only impractical but unnecessarily for elderly population to maintain and enhance trunk strength, the purpose of our study is to improve trunk strength through enhanced neuromuscular control, i.e. coordination ability. This paper focuses on addressing the first question: how to quantify trunk strength in term of coordination ability. Given that the neuro-musculo-skeletal complexity of the trunk is not well understood so far, we use a data-driven approach that combines pervasive computing technologies and data mining techniques.

First, we cooperated with dance professionals to defined two kinds of standard movements, i.e., Waltz Rotation (WR) and Merengue Shake (MS), as well as their ideal forms. Second, we investigated the feasibility of using two portable and widely available devices, i.e. accelerometer (embedded in iPod) and Nintendo Wii balance board (WBB), in evaluating trunk strength in view point of coordination ability. The former measures acceleration of a motion in three orthogonal directions, while the latter measures the coordinates of the centre of gravity trajectory during a movement. Both measures are used for quantifying coordination ability. We extracted time and frequency domain features from these data and investigated the differentiating capability of the features using Fisher Score [7]. We found that the features of accelerometers were more powerful in differentiating coordination ability of body trunk in comparison to those of WBB, suggesting that accelerometer could be a better candidate than WBB in achieving the goal of this study.

The contributions of this work were as follows:

- We set out a new direction for quantifying trunk strength in the context of healthy aging. Shifting the focus from muscle mass/strength to coordination ability fit in better to

the need and capability of elderly population.

- We proposed a pervasive computing approach that utilizes portable devices for evaluating trunk strength as alternatives to bulky devices (such as motion capture system and force plates) that were traditionally used in sports science.
- We investigated the feasibility of using two most widely available portable devices in achieving the research goal. The results show that accelerometer may be a good candidate for achieving the goal of the study.

2. Methods and Procedures

2.1 Standard Movements

The first step in the study was to define standard movements that (1) require smooth coordination of body trunk and thus can be used to evaluate coordination ability, and (2) are easy and safe to perform so that anybody (especially the elderly population) could do the movements. Since dancesports involves many movements that require whole body coordination [8], we discussed with dancesports professionals to define the two standard movements and their ideal forms.

2.1.1 Standard Movement 1: Waltz Rotation (WR)

As is shown in Figure 1, Waltz Rotation (WR) starts with feet apart at shoulder's width. The performer is required to rotate the upper body slowly while using hip joints as the supporting point. The supporting foot should not be moved and the heel of the other foot can be lifted up. The small toe of the supporting foot should cling to the floor

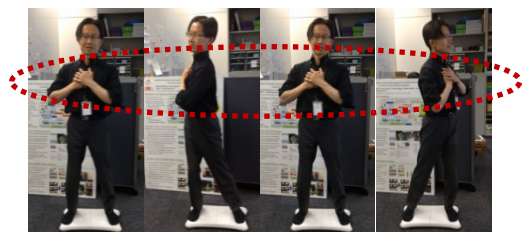


Figure 1. Standard movement 1: Waltz Rotation (WR).

2.1.2 Standard Movement 2: Merengue Shake (MS)

As is shown in Figure 2, Merengue Shake (MS) starts with feet together. The performer is required to switch center of gravity between two legs by alternating between bending and strengthening the knees, with the toes of the bending knee pointing the floor. Head should be facing forward and kept stable.

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Figure 2. Standard movement 1: Merengue Shake (MS).

2.2 Data Collection

The first step in the study was to define standard movements that (1) require smooth coordination of body trunk and thus can be used to evaluate coordination ability, and (2) are easy and safe to perform so that anybody (especially the elderly population) could do the movements. Since dancesports involves many movements that require whole body coordination [8], we discussed with dancesports professionals to define the two standard movements and their ideal forms.

2.2.1 Participants

We recruited six injury free adults with a range of ages (2 males and 4 females, year range: 28-65) for the measurement. No participant reported a major back or lower limb pathology, use of medication, or a history of neurologic disease that may influence neuromuscular control. Each participant gave informed consent to participate in the trial after approval had been obtained from the Human Research Ethics Committee at the National Institute of Advanced Industrial Science and Technology.

2.2.2 Devices

We used two kinds of devices simultaneously in the trial to collect data from participants: an iPod with embedded accelerometer and a Nintendo Wii Balance Board (WBB). The triaxial accelerometer embedded in iPod has been widely used to collect acceleration data during movements [9]. In this study, the dynamic range of the accelerometer is $\pm 2.3g$, and the sampling frequency of 50Hz was selected for this study. The output of an accelerometer includes time series of acceleration values in three orthogonal directions, i.e. Acc_X , Acc_Y , Acc_Z and the root sum of squares (RSS) $Acc_{RSS} = \sqrt{Acc_X^2 + Acc_Y^2 + Acc_Z^2}$. WBB is a reasonably accurate tool to measure center of pressure (CoP) in home settings as an alternative to force platform [10]. The Wii board used in this study has a useable surface of 45cm x 26.5 cm and was located on the laboratory floor. The trajectory of CoP , sampled at 100Hz, was visualized on the screen of a laptop using third party software named FitTri. The output of a WBB includes the coordinates of CoP , i.e., CoP_X and CoP_Y .

2.2.3 Measurement Protocol

As is shown in Figure 1 and 2, participants were asked to stand on the WBB and press an iPod on the chest while performing the required movements. Each participant was instructed on the correct form of the standard movements and then was asked to perform a series of six movements subsequently according to the following order: $WR_1 \rightarrow MS_1 \rightarrow WR_2 \rightarrow MS_2 \rightarrow MS_3 \rightarrow WR_3$. We also took videos using a camera. After the trials, the videos were shown to a dancesports professional for labeling them with "good" or "poor" coordination ability.

2.2.4 Data Labelling

The ground truth on truck coordination ability is difficult to obtain, largely due to its obscure definition of coordination itself. Alternatively, we invited a dancesports professional to evaluate the coordination ability of the participants by watching the video records, and we used his evaluation as the ground of truth.

2.3 Data Analysis

2.3.1 Data Preprocessing

For accelerometer data, we first smoothed the data using a median filter with $n=5$ (n is the order of the median filter) to remove any abnormal noise spikes produced by the accelerometers as was recommended in [11]. Then a high-pass filter with cut-off frequency at 0.25 Hz was employed to filter out the acceleration components due to gravity (GA) from the median-filtered signal [12]. The output of the filter is the body acceleration (BA) component. For WBB data, we removed the first and the last 1000 data points to eliminate the interference of other movements before and after the standard movements to remove the impact of residual movements.

2.3.2 Feature Extraction

In total 125 features were extracted, 107 from acceleration data and 18 from Wii Balance Board. These features were selected in line with standard motion detection [12] and center of pressure analysis [13]. Time domain features were derived directly from sensor data and were typically statistical measures, whereas frequency domain features were derived from the fast Fourier transform (FFT) of sensor data. A full list of the features is summarized in Table 1.

Devices	Features
Accelerometer (107 features)	<ul style="list-style-type: none"> - Maximum, minimum, mean, median, standard deviation, median absolute deviation (MAD), skewness, kurtosis, 10th/25th/50th/75th/90th percentile, root mean square (RMS) of Acc_X, Acc_Y, Acc_Z, and Acc_{RSS} - Correlation between Acc_X and Acc_Y, between Acc_X and Acc_Z, between Acc_Z and Acc_Y - Principal/fundamental/maximum/median/mean/peak frequency of Acc_X, Acc_Y, Acc_Z - Total/mean power of Acc_X, Acc_Y, Acc_Z - Magnitude of the first five components of FFT analysis - Frequency domain entropy of Acc_X, Acc_Y, Acc_Z, and Acc_{RSS}
WBB (18 features)	<ul style="list-style-type: none"> - Maximum, minimum, mean, range, standard deviation, total length of CoP_X and CoP_Y - Range of CoP_X - Range of CoP_Y - Rectangular area - Deflection ratio of the 1st, 2nd, 3rd, 4th coordinate plane

Table 1. Table captions should be placed below the table.

2.3.3 Feature Ranking

Given that there was only limited number of instances in our dataset, we chose Fisher Score to achieve a trade-off between speed and comprehensiveness in selecting discriminative features. Fisher score is a simple yet effective method for supervised feature selection, which selects each feature independently according to their scores under the Fisher criterion and gives an important order of all features [7].

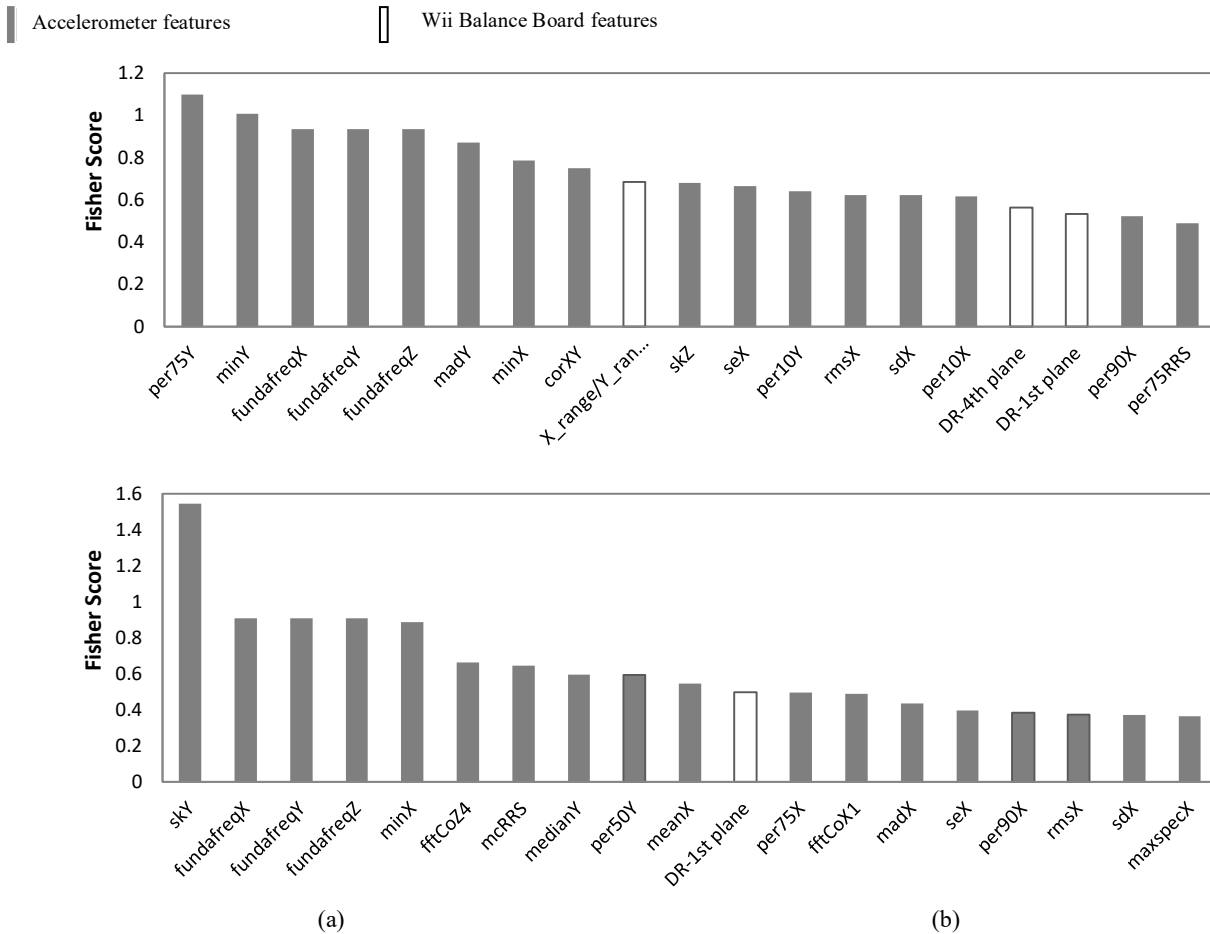


Figure 3. Top 20 features for evaluating coordination ability of (a) Waltz Rotation and (b) Merengue Shake. The top 3 features for Waltz Rotation were 75th percentile of acceleration in Y direction, minimal of acceleration in Y direction, and fundamental frequency of acceleration in X direction. The top 3 features for Merengue Shake were skewness of acceleration in Y direction, fundamental frequency of acceleration in X direction, and fundamental frequency of acceleration in Y direction.

Let $x_{i,j}$ denote the j -th feature of the i -th instance. The Fisher Score of the j -th feature is defined as:

$$F(j) = \frac{(\bar{x}_j^{(+)} - \bar{x}_j)^2 + (\bar{x}_j^{(-)} - \bar{x}_j)^2}{\frac{1}{n^{(+)} - 1} \sum_{i=1}^{n^{(+)}} (x_{i,j}^{(+)} - \bar{x}_j^{(+)})^2 + \frac{1}{n^{(-)} - 1} \sum_{i=1}^{n^{(-)}} (x_{i,j}^{(-)} - \bar{x}_j^{(-)})^2} \quad (1)$$

where $n^{(+)}$ and $n^{(-)}$ are the number of positive and negative instances respectively; \bar{x}_j , $\bar{x}_j^{(+)}$, $\bar{x}_j^{(-)}$ are the average of the j -th feature of the whole instance set, the positive-labeled and the negative-labeled instance sets; $x_{i,j}^{(+)}$ is the j -th feature of the i -th positive instance, while $x_{i,j}^{(-)}$ is the j -th feature of the i -th negative instance. The numerator denotes the inter-class variance, while the denominator is the sum of the variance within each class. A larger Fisher Score indicates that the feature has more differentiating power

3. Results

After labelling all recorded movements, we found that WR was easier to perform than MS, as the former was dominated by negative samples whereas in the latter positive and negative samples share half-and-half. We ranked all features extracted from the two kinds of devices according to Fisher Score and the top 20 features for evaluating the coordination ability in performing Waltz Rotation (WR) and Merengue Shake (MS) are

shown in Figure 3. Most of the top 20 features were from accelerometer, though this may be due to the fact that we extracted much less features from WBB in the first place. However, the best feature of WBB was less than half of the best feature from accelerometer, indicating that the differentiating power of WBB features was weaker than accelerometer features. The fundamental frequencies of all three components of acceleration (i.e. X, Y, Z components) were important features for both movements, while the skewness of Y was found to be a very useful feature for MS.

4. Discussions

The preliminary results presented above provided two major implications. First, accelerometer could be a good candidate for easy and ubiquitous evaluation of motion quality comparing to WBB, as the features with the highest Fisher scores were all accelerometer features. Second, fundamental frequency of acceleration components and especially acceleration in Y direction were important features in evaluating coordination ability. However, the numerical relationship between the features and coordination ability requires further investigation.

It is also worth noting that current study has the following limitations. First, we did not investigate the optimized location for placing sensors. The placement of motion capture markers and accelerometer was heuristic. Second, our participant cohort was small and the data collected were not sufficient to draw

general conclusions. Third, the quality of the movements was evaluated and labeled by only one dance professional thus personal bias was unavoidable in the evaluation. We will address the three limitations in our future study.

5. Conclusions

The overarching goal of our study was to develop pervasive computing technologies for evaluating and improving trunk strength for healthy aging. In this paper, we first presented two standard movements, i.e. Waltz Rotation and Merengue Shake, and their ideal forms. We then investigated the feasibility of using accelerometer embedded in iPod and Nintendo Wii balance board (WBB) in differentiating good and poor coordination ability. After collecting acceleration data and center of gravity trajectories of the movements from six participants using these two types of devices, we extracted features in time and frequency domain from the data and ranked them using Fisher Score. The preliminary results showed that accelerometer features have stronger differentiating power than WBB features, suggesting that accelerometer may be a better candidate than WBB in evaluating coordination ability of body trunk. Moreover, the fundamental frequencies of acceleration as well as the skewness of acceleration in Y direction were the strongest features. However, the numerical relationship between the features and coordination ability requires further investigation. The results presented in this paper, though preliminary in nature, provided constructive implications for the further development of mobile health technologies that facilitate trunk strength improvement in elderly population.

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